US009307666B2

(12) **United States Patent**
Tokuyama et al.

(10) **Patent No.: US 9,307,666 B2**
(45) **Date of Patent: Apr. 5, 2016**

(54) **ELECTRIC CIRCUIT DEVICE, ELECTRIC CIRCUIT MODULE, AND POWER CONVERTER**

(71) Applicant: **Hitachi, Ltd.**, Chiyoda-ku, Tokyo (JP)

(72) Inventors: **Takeshi Tokuyama**, Hitachi (JP); **Kinya Nakatsu**, Hitachinaka (JP); **Atushi Kawabata**, Hitachi (JP)

(73) Assignee: **Hitachi, Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 153 days.

(21) Appl. No.: **14/261,626**

(22) Filed: **Apr. 25, 2014**

(65) **Prior Publication Data**

US 2014/0233204 A1 Aug. 21, 2014

Related U.S. Application Data

(63) Continuation of application No. 13/241,600, filed on Sep. 23, 2011, now Pat. No. 8,743,548, which is a continuation of application No. 12/715,025, filed on Mar. 1, 2010, now Pat. No. 8,081,472, which is a continuation of application No. 11/740,622, filed on Apr. 26, 2007, now Pat. No. 7,961,472.

(30) **Foreign Application Priority Data**

Apr. 27, 2006 (JP) 2006-123835

(51) **Int. Cl.**
H05K 7/20 (2006.01)
H05K 7/02 (2006.01)
H02M 7/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H05K 7/02*** (2013.01); ***H02M 7/003*** (2013.01); *H01L 2224/32245* (2013.01);

(Continued)

(58) **Field of Classification Search**
CPC H05K 7/20; H05K 7/2089; H01L 24/33
See application file for complete search history.

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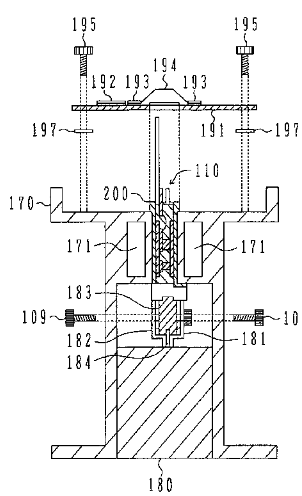
Primary Examiner — Gregory Thompson
(74) *Attorney, Agent, or Firm* — Crowell & Moring LLP

(57) **ABSTRACT**

The present invention provides an electric circuit device in which it is possible to achieve simultaneously the improvement of cooling performance and reduction in operating loss due to line inductance. The above object can be attained by constructing multiple plate-like conductors so that each of these conductors electrically connected to multiple semiconductor chips is also thermally connected to both chip surfaces of each such semiconductor chip to release heat from the chip surfaces of each semiconductor chip, and so that among the above conductors, a DC positive-polarity plate-like conductor and a DC negative-polarity plate-like conductor are opposed to each other at the respective conductor surfaces.

6 Claims, 30 Drawing Sheets



(52) **U.S. Cl.**
CPC *H01L 2224/45124* (2013.01); *H01L 2224/48091* (2013.01); *H01L 2224/48247* (2013.01); *H01L 2224/73215* (2013.01); *H01L 2224/73265* (2013.01); *H01L 2924/1305* (2013.01); *H01L 2924/13055* (2013.01); *H01L 2924/13091* (2013.01); *H01L 2924/3025* (2013.01); *H01L 2924/30107* (2013.01)

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FIG. 1

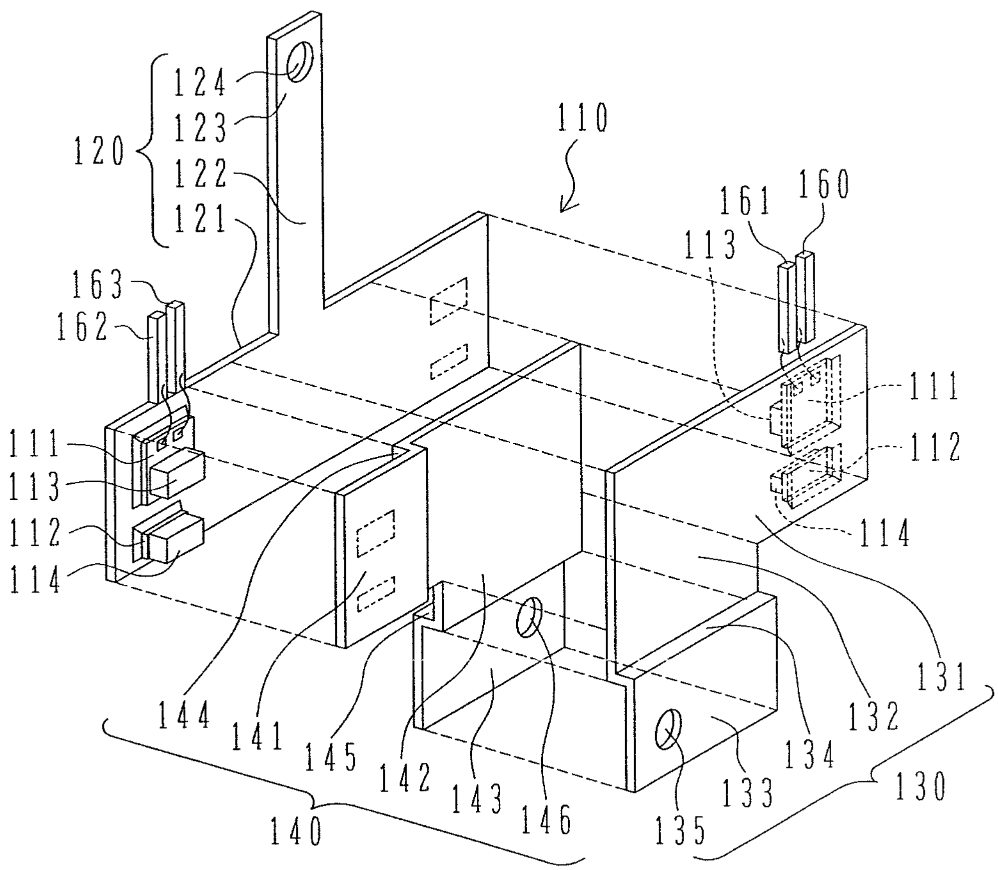
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FIG. 2

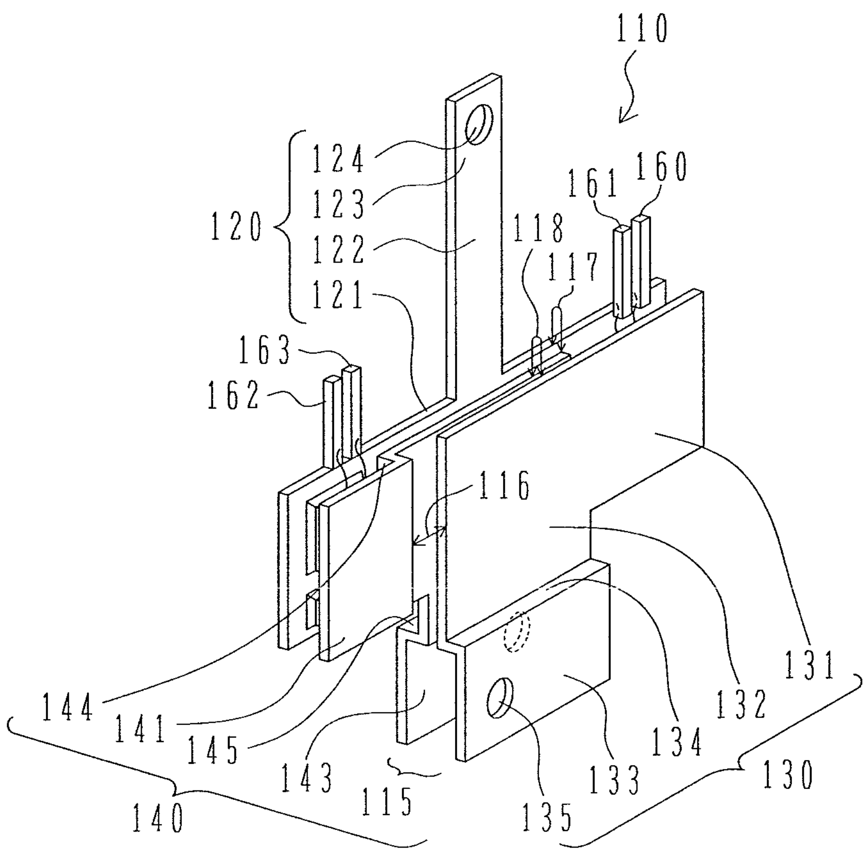
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FIG. 3

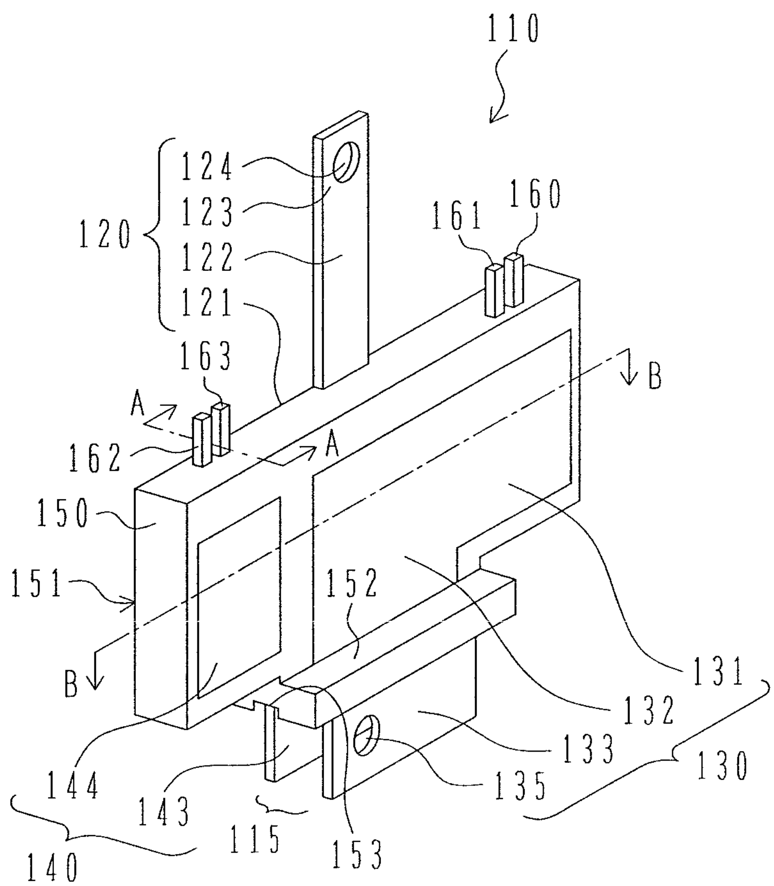
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FIG. 4

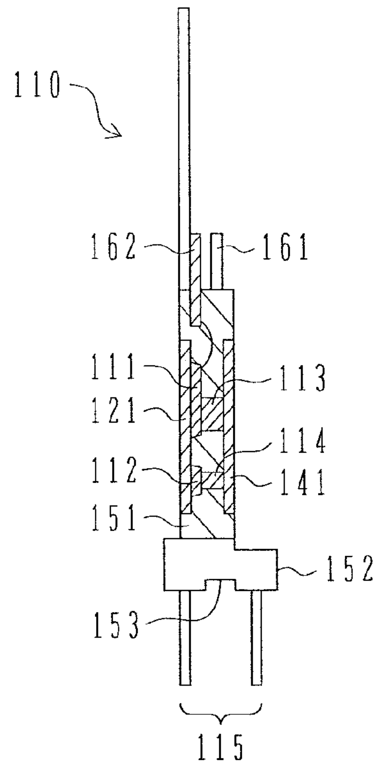

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FIG. 5

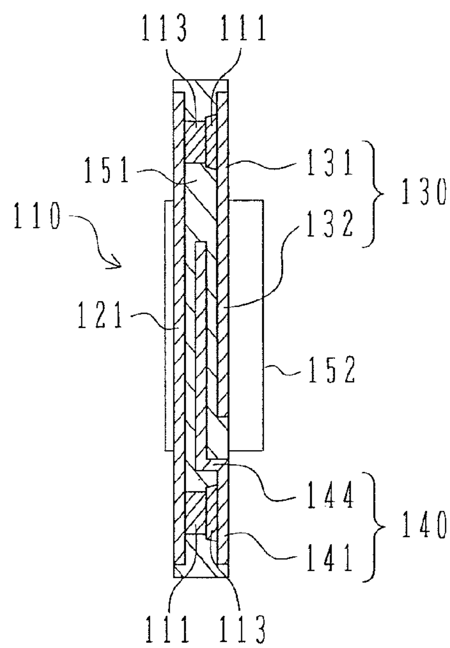

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FIG. 6

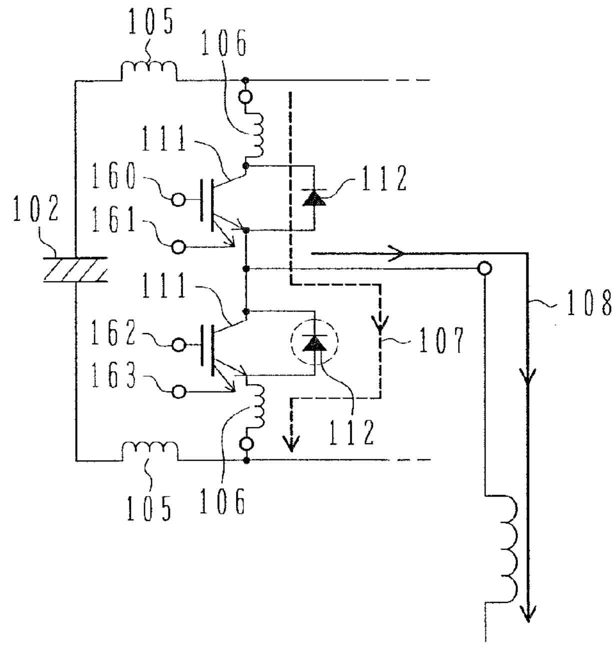
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FIG. 7

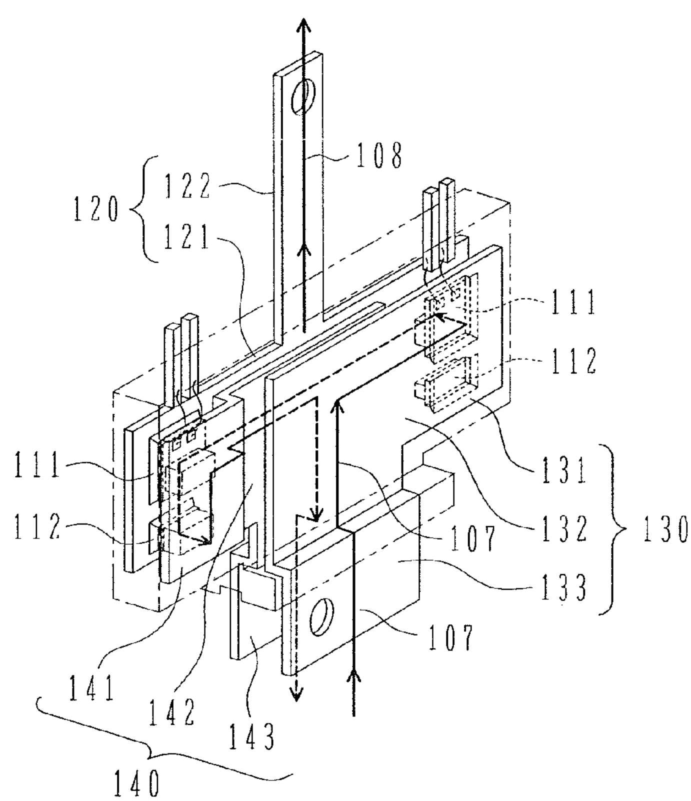
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FIG. 8

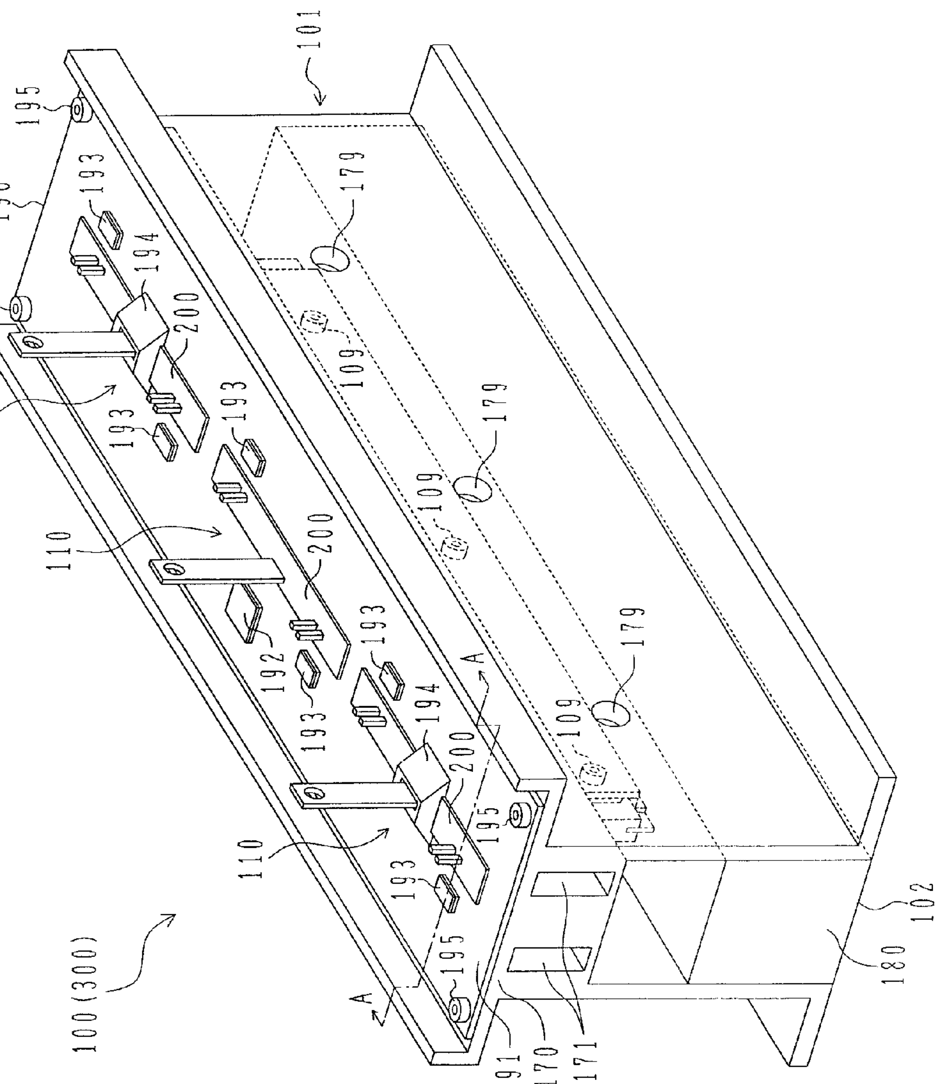
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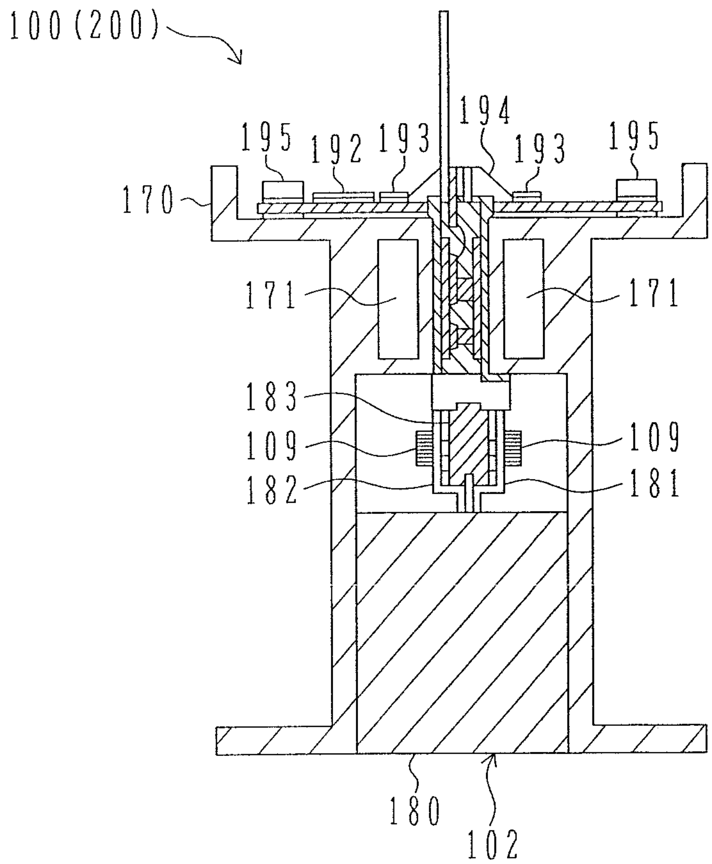
FIG. 9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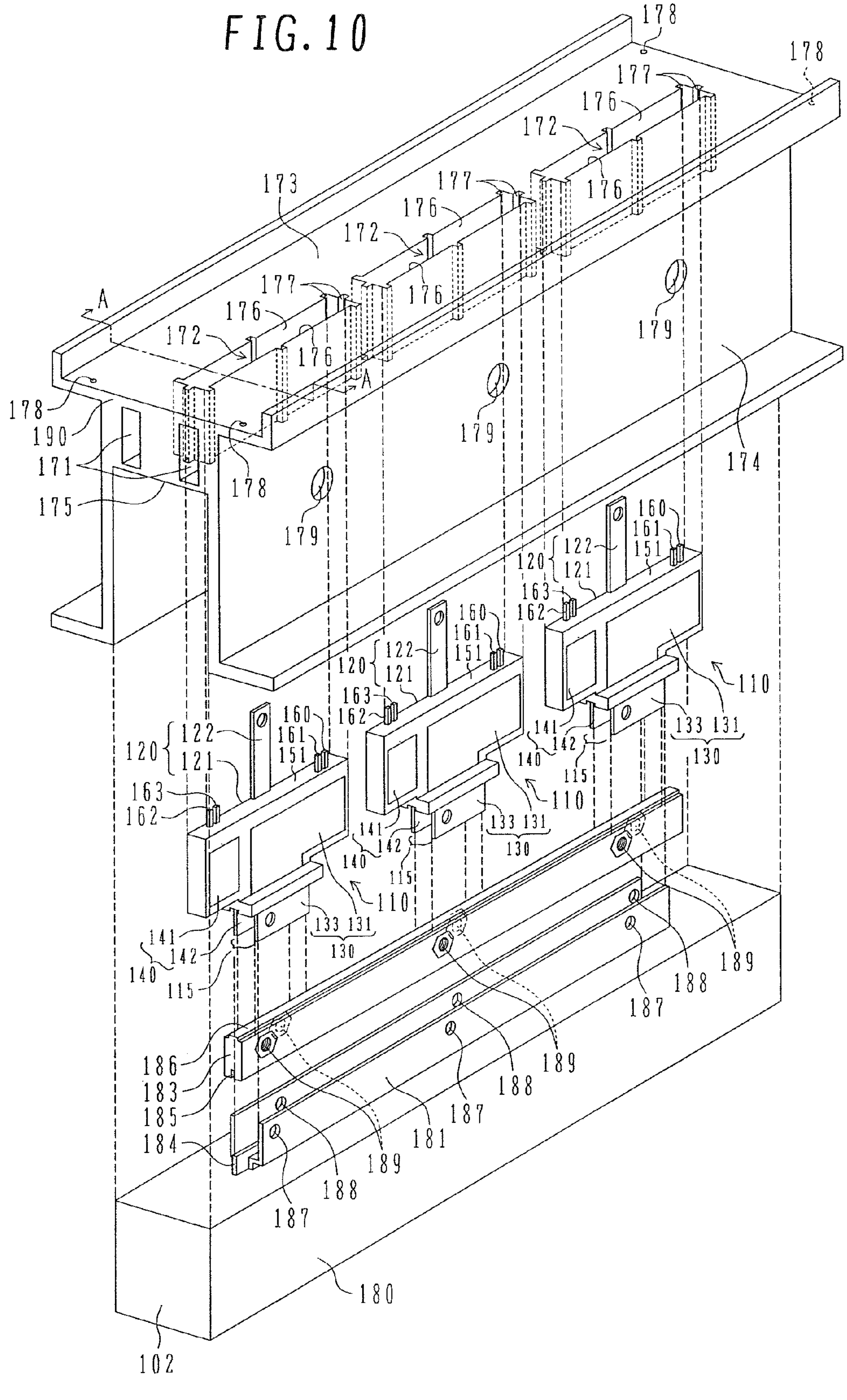
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FIG. 11

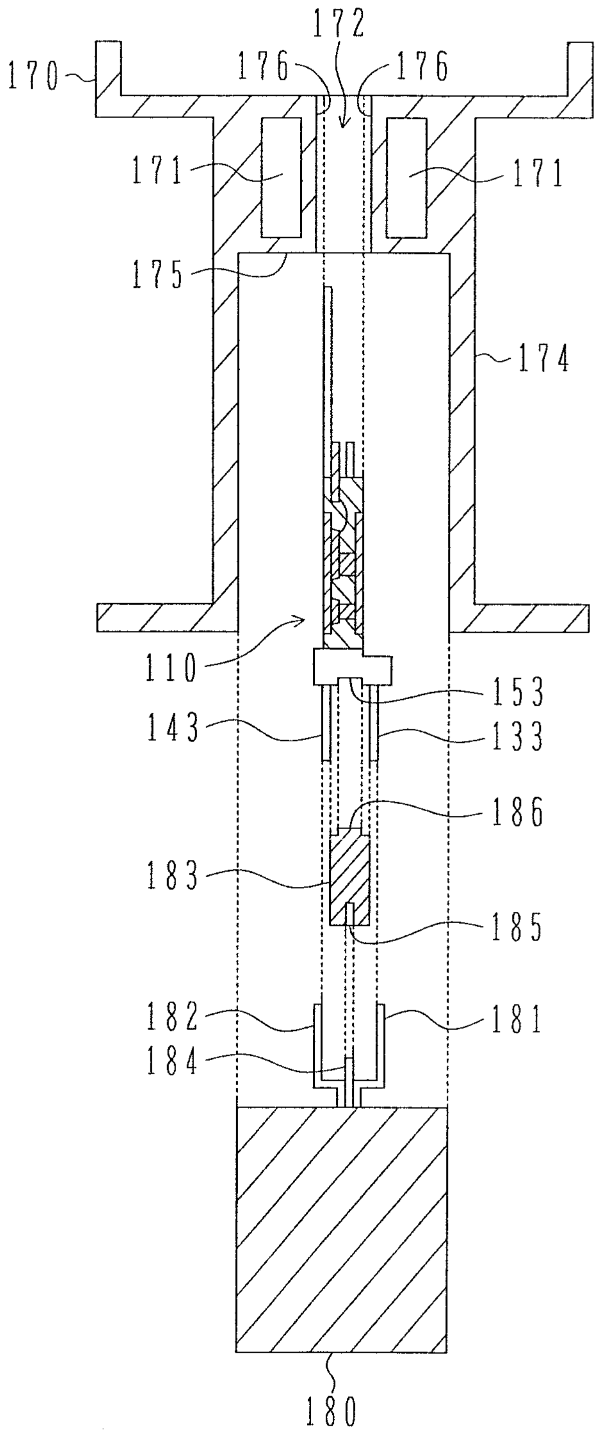

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FIG.12

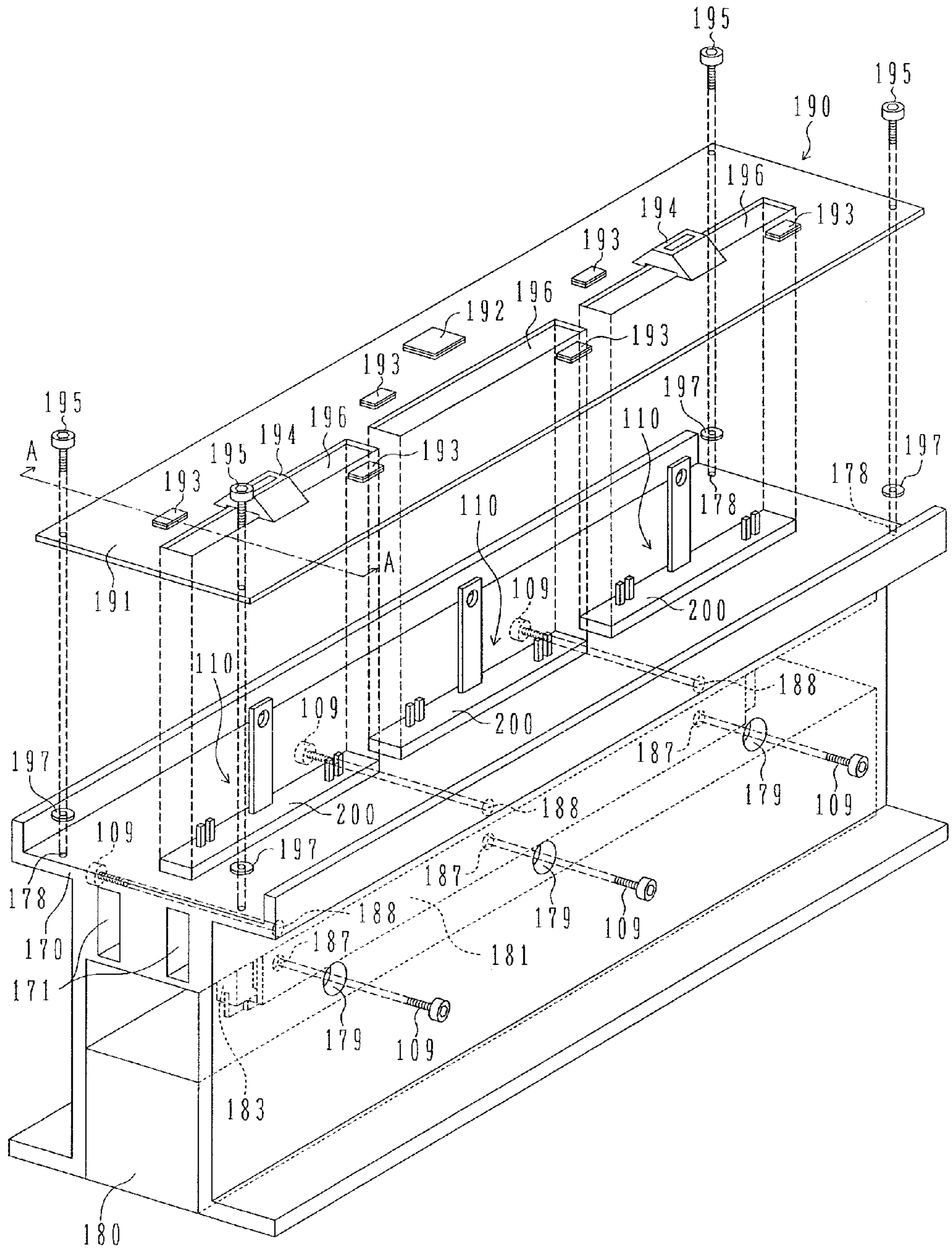
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FIG. 13

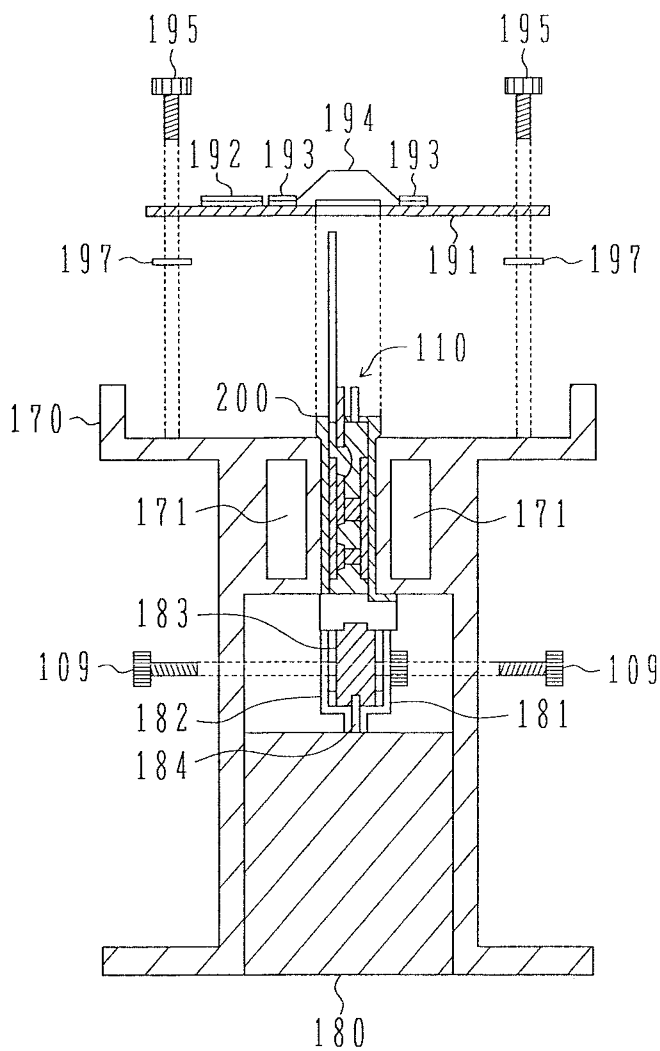
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FIG. 14

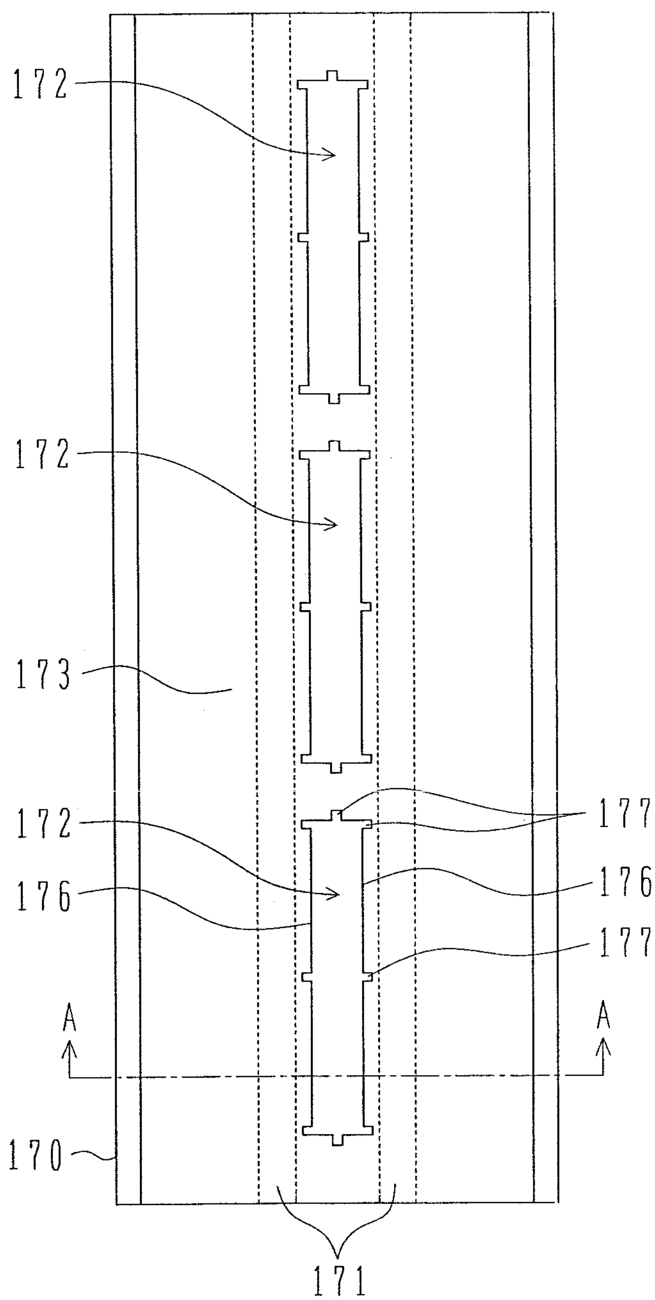


FIG. 15

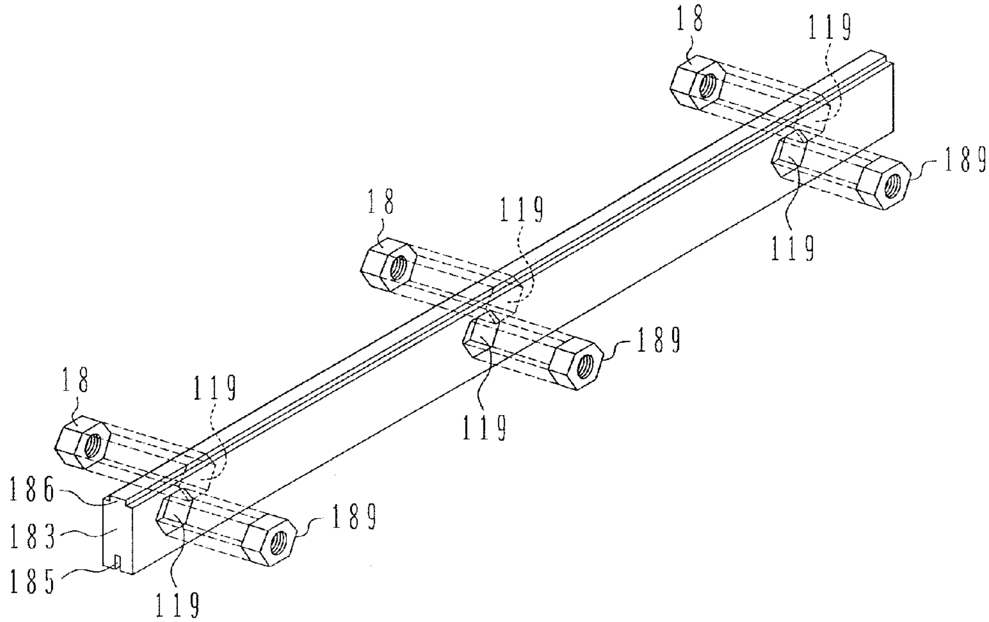


FIG. 16

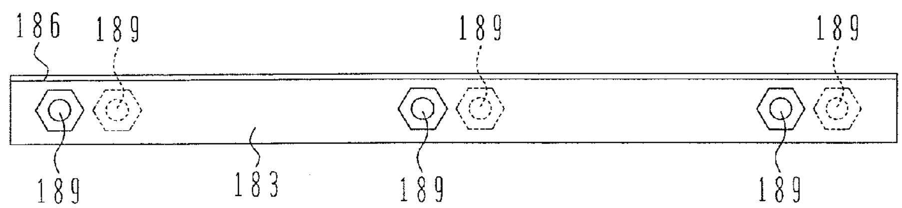
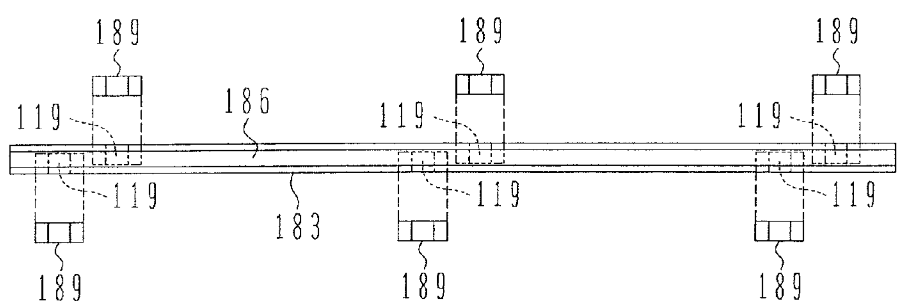


FIG. 17



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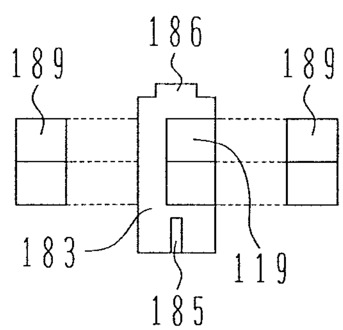

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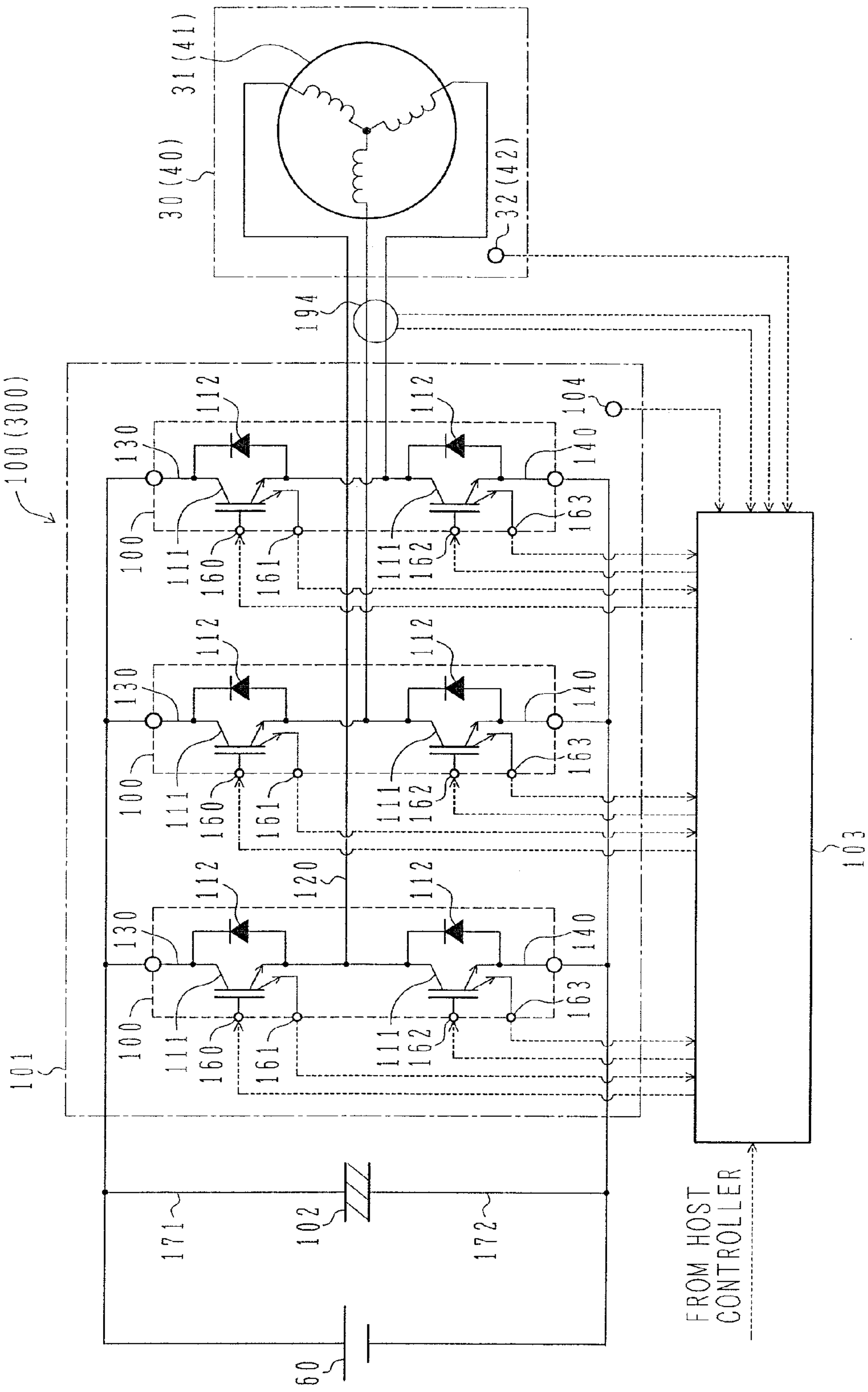
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FROM HOST CONTROLLER

FIG. 20

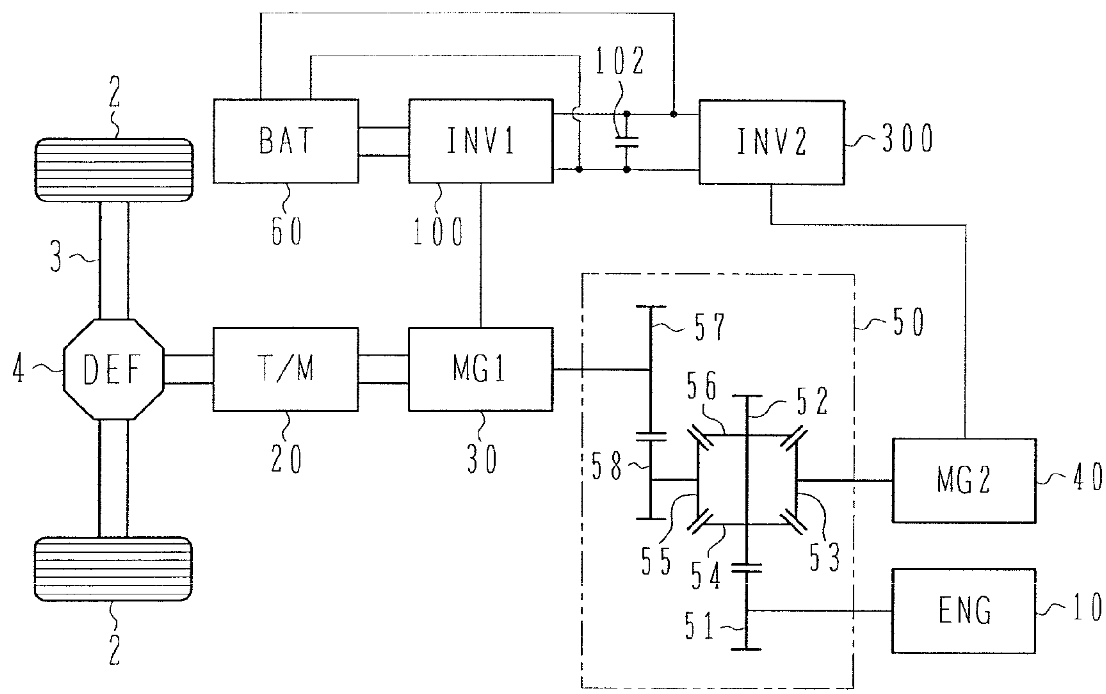
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FIG. 21

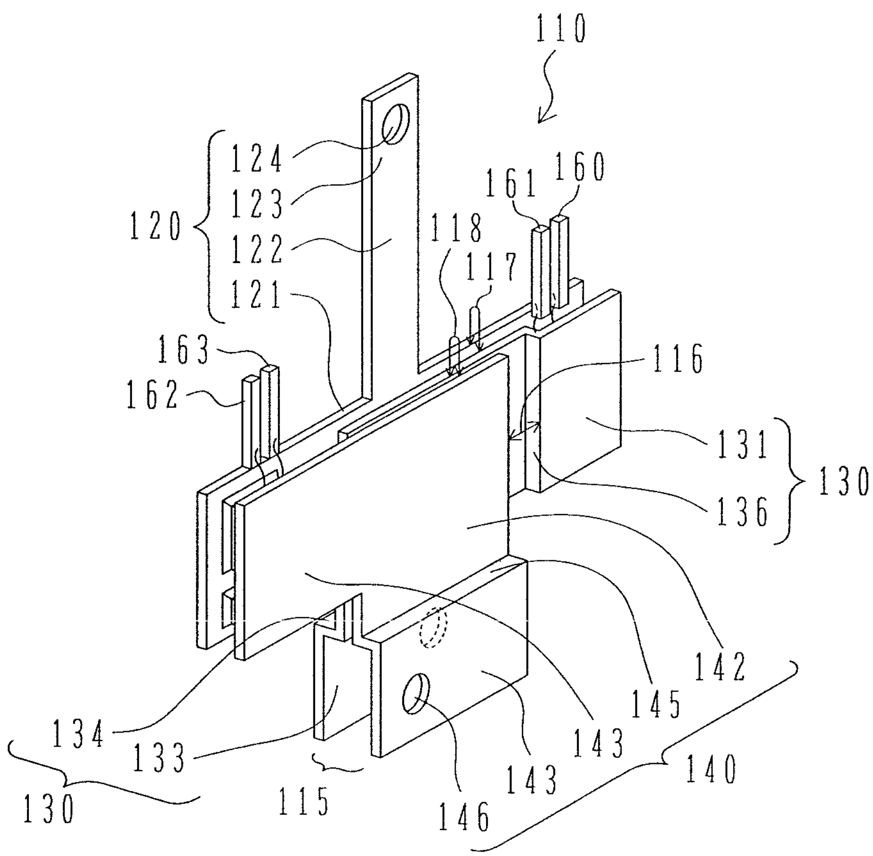
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FIG. 22

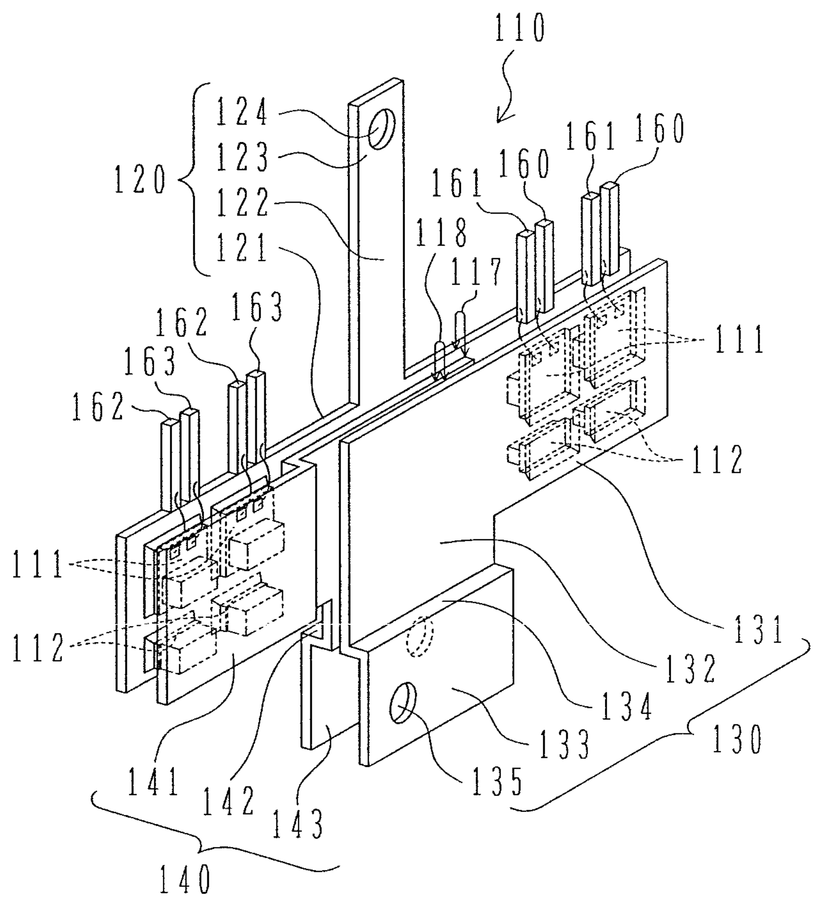
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FIG. 23

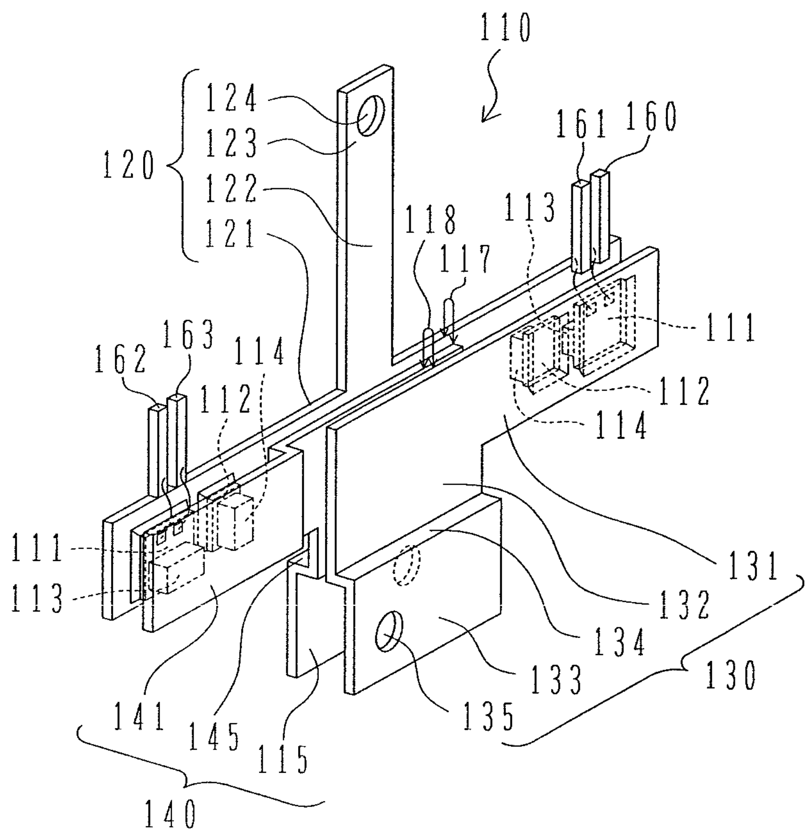
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FIG. 24

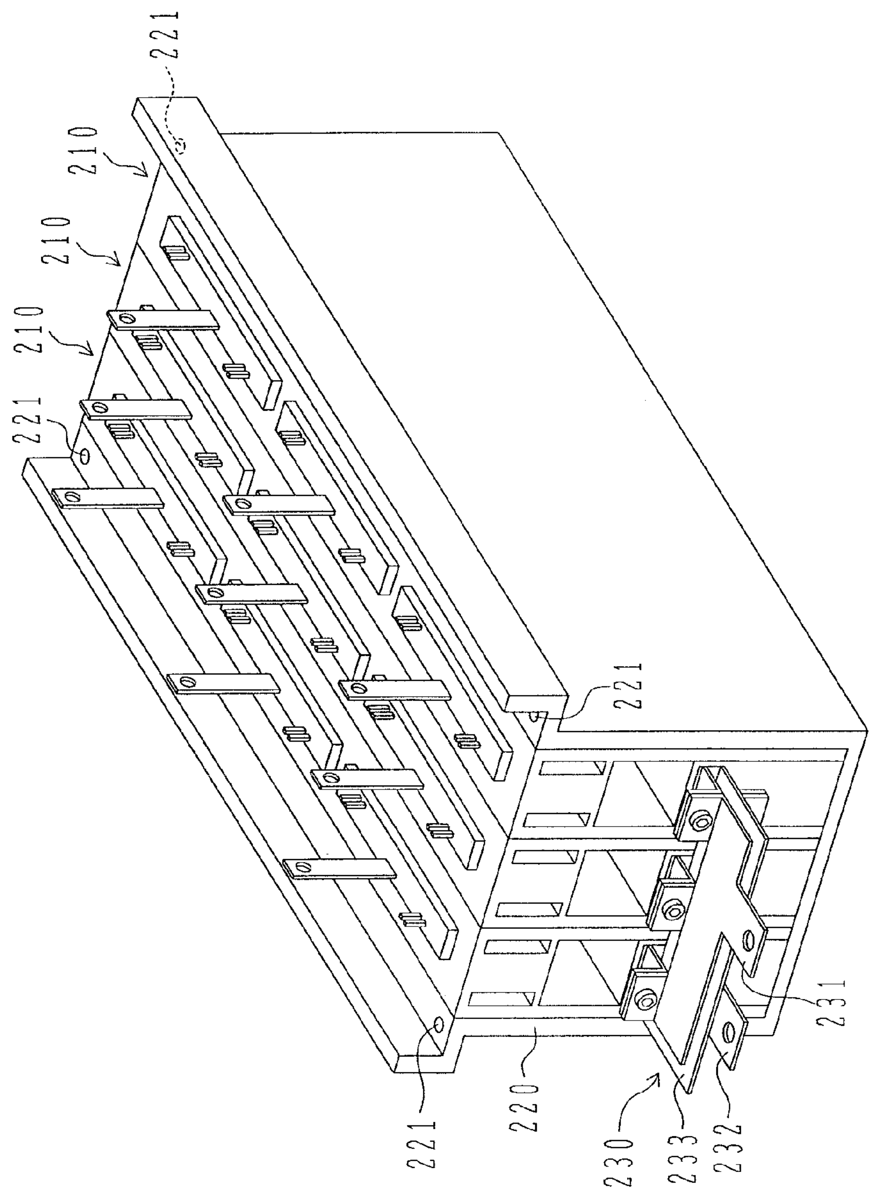

FIG. 25

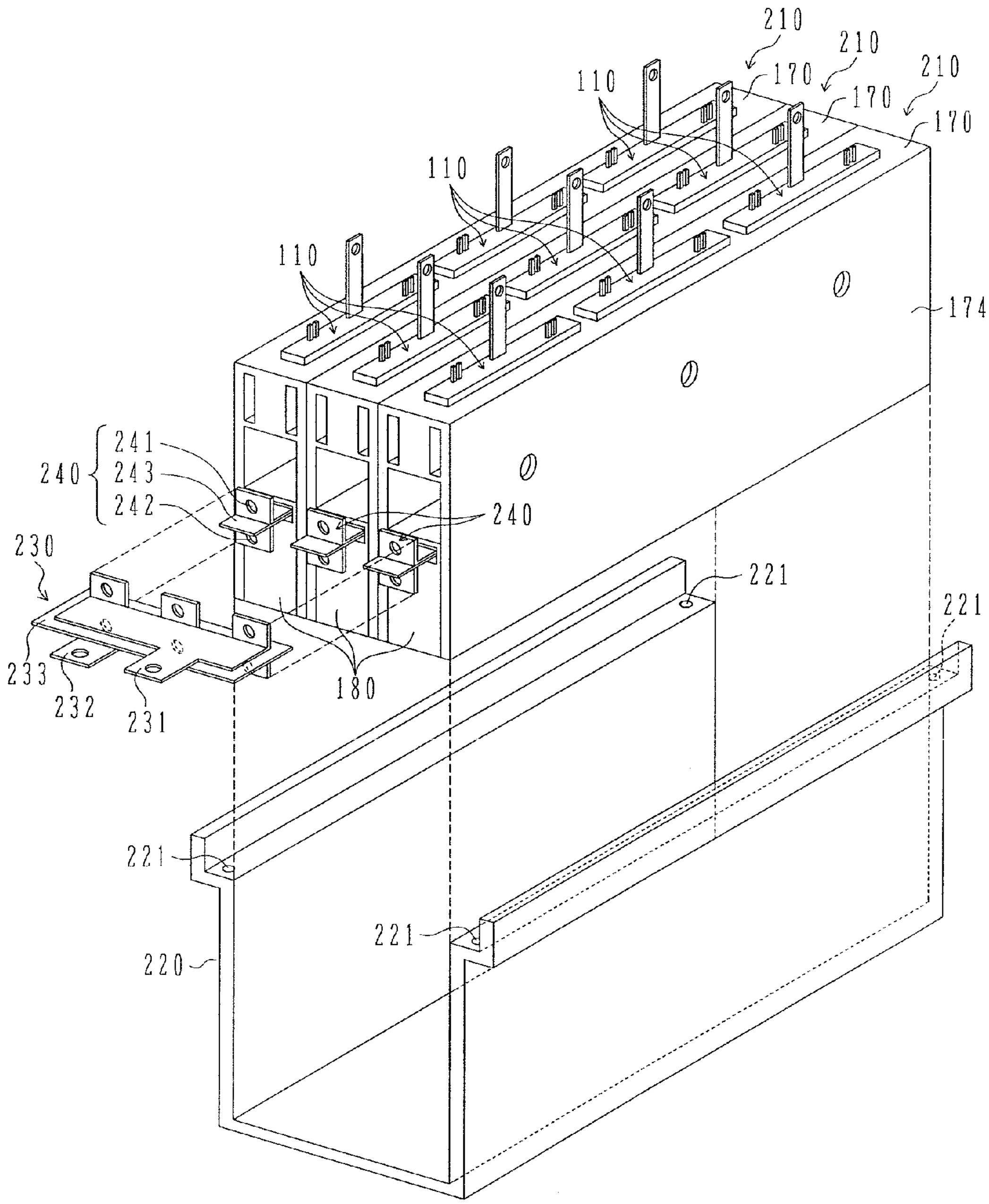
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FIG. 26

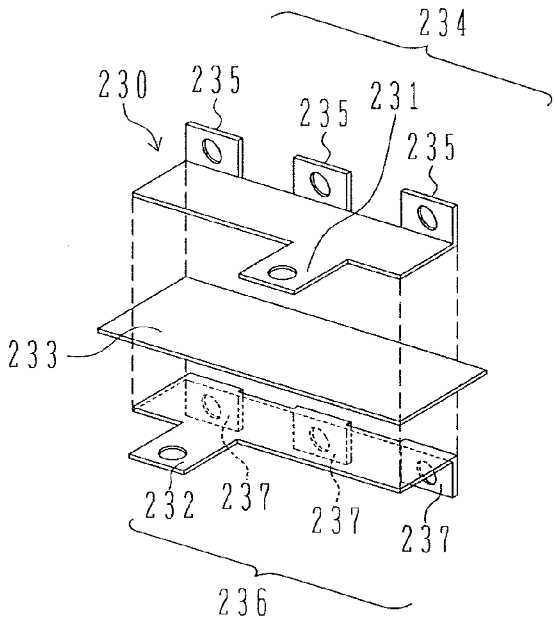
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FIG. 27

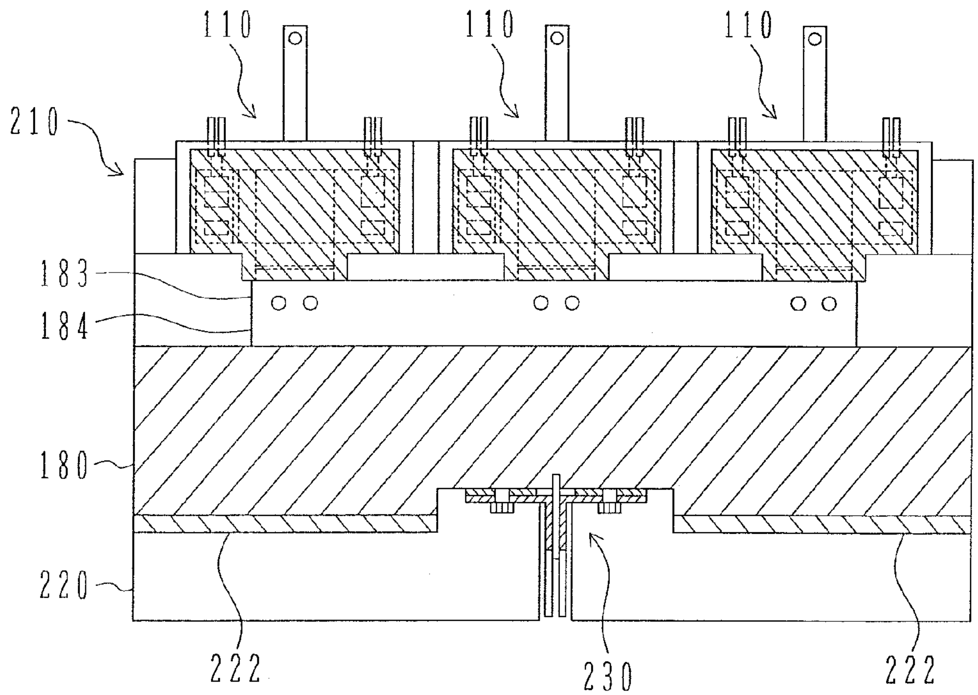
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FIG. 28

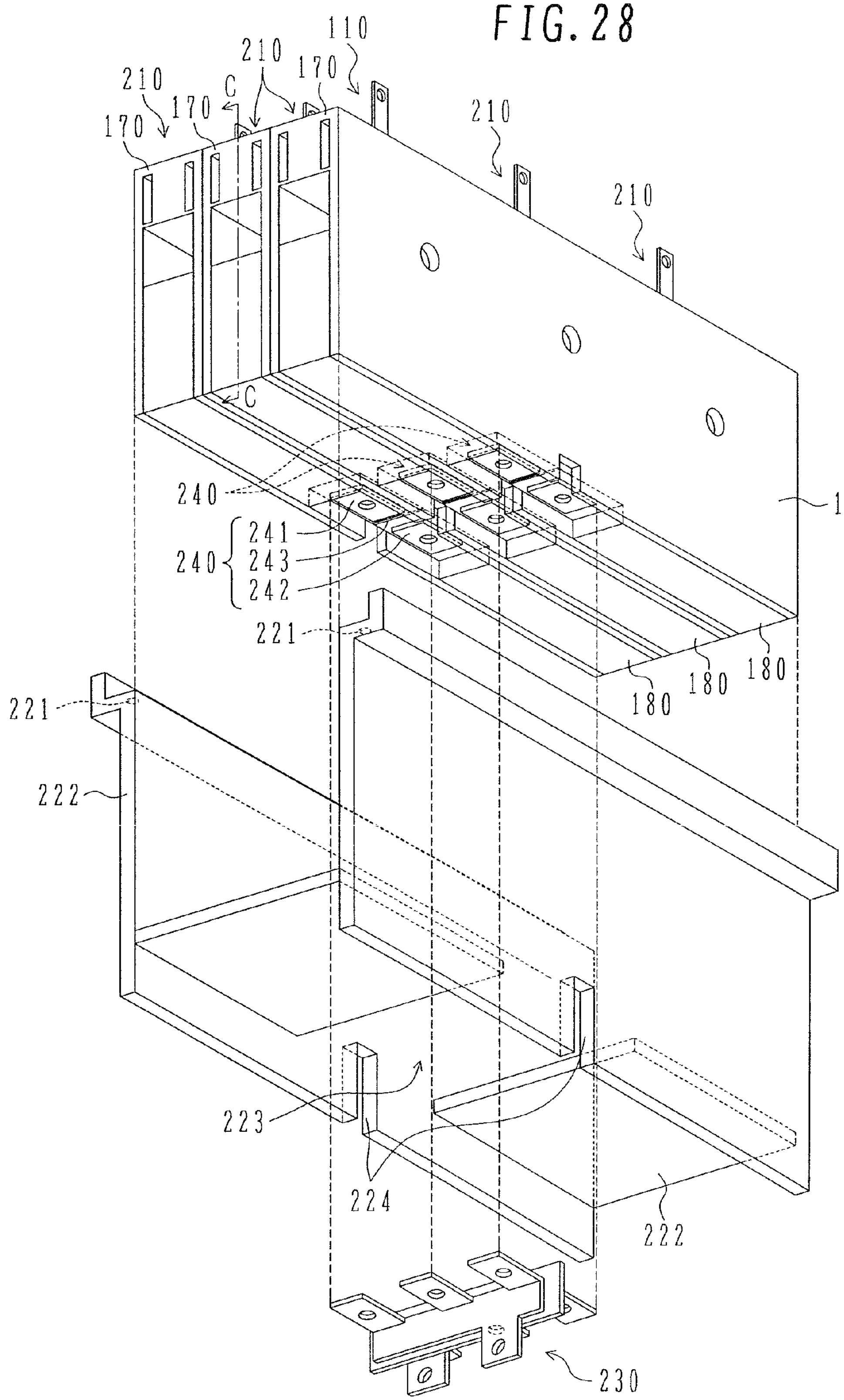
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FIG. 29

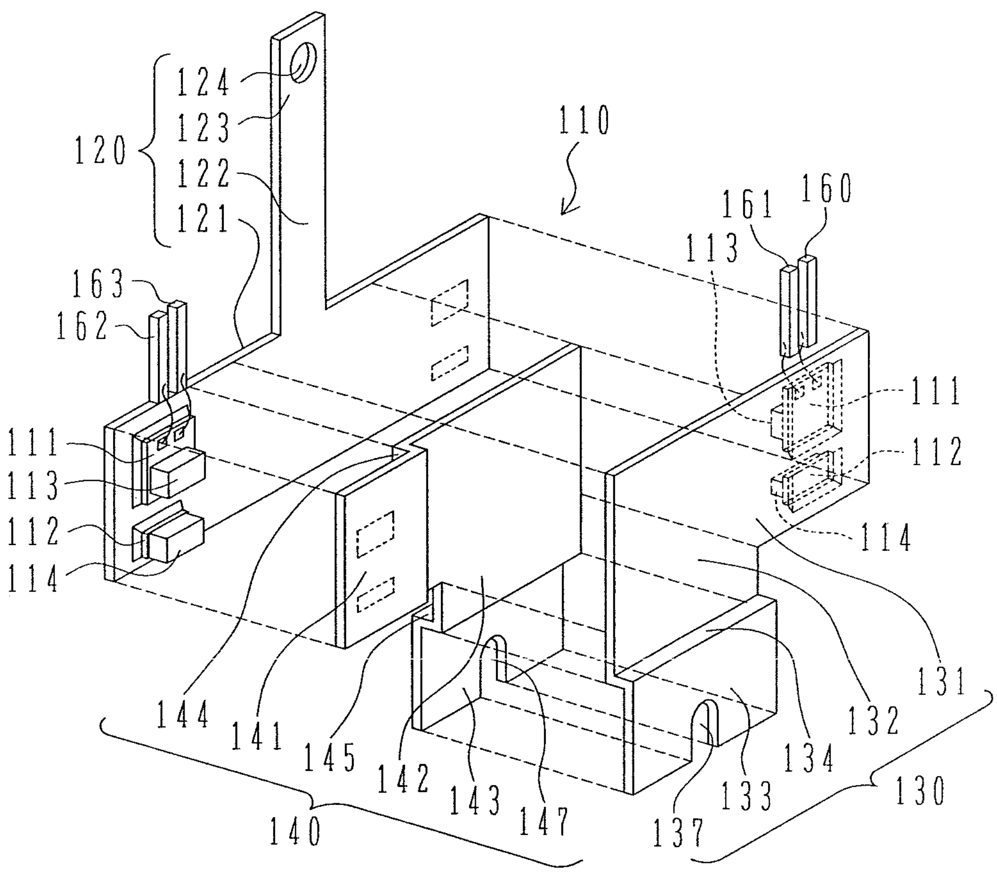

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FIG. 30

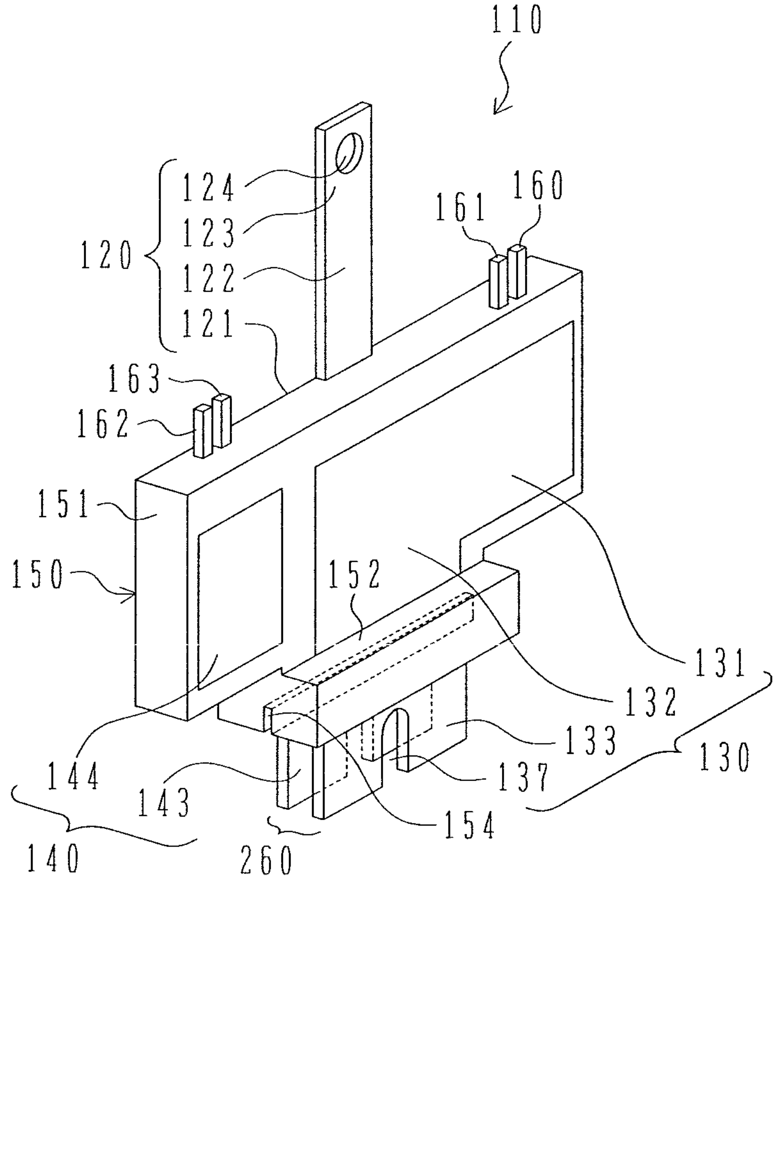
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FIG. 31

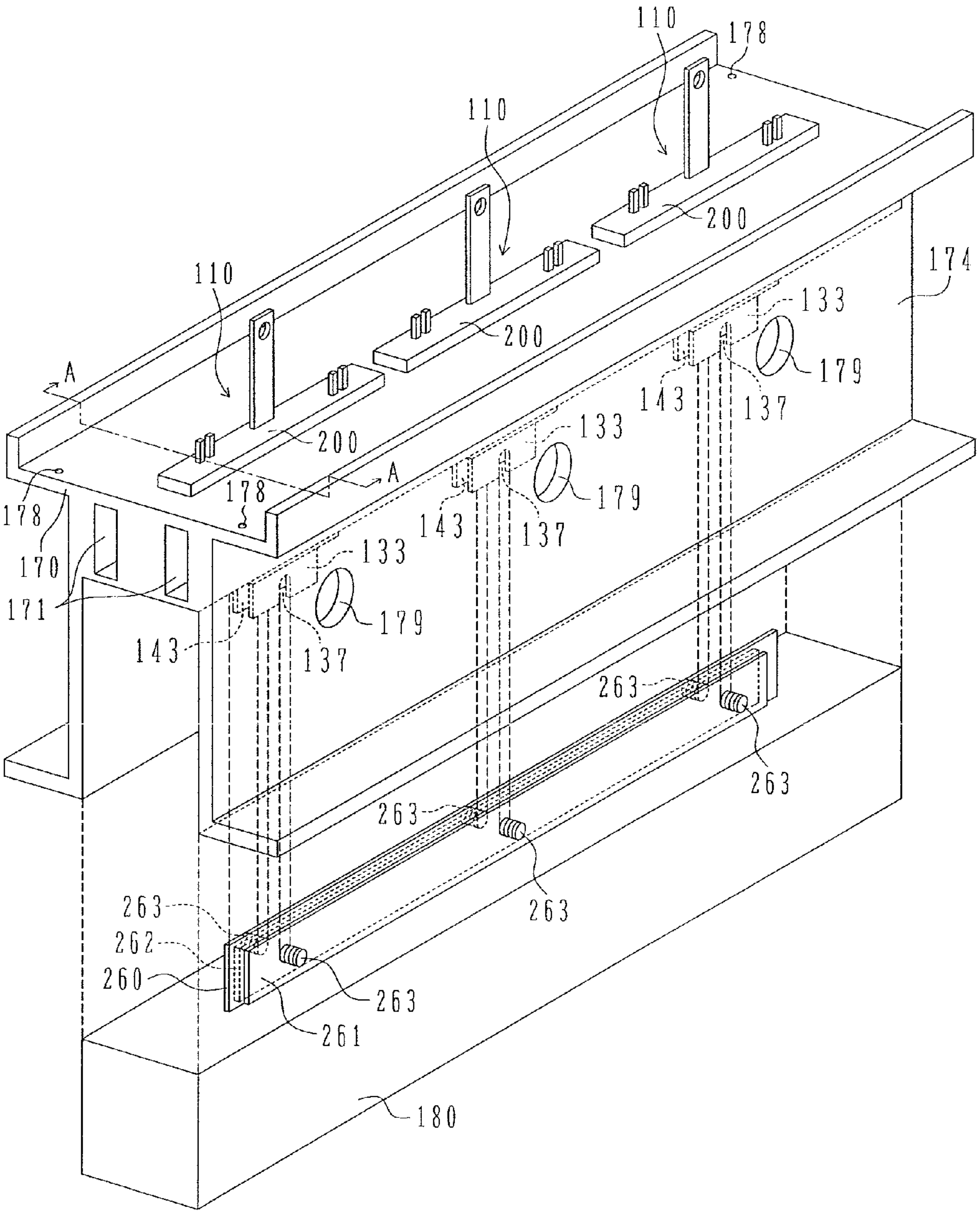
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FIG. 32

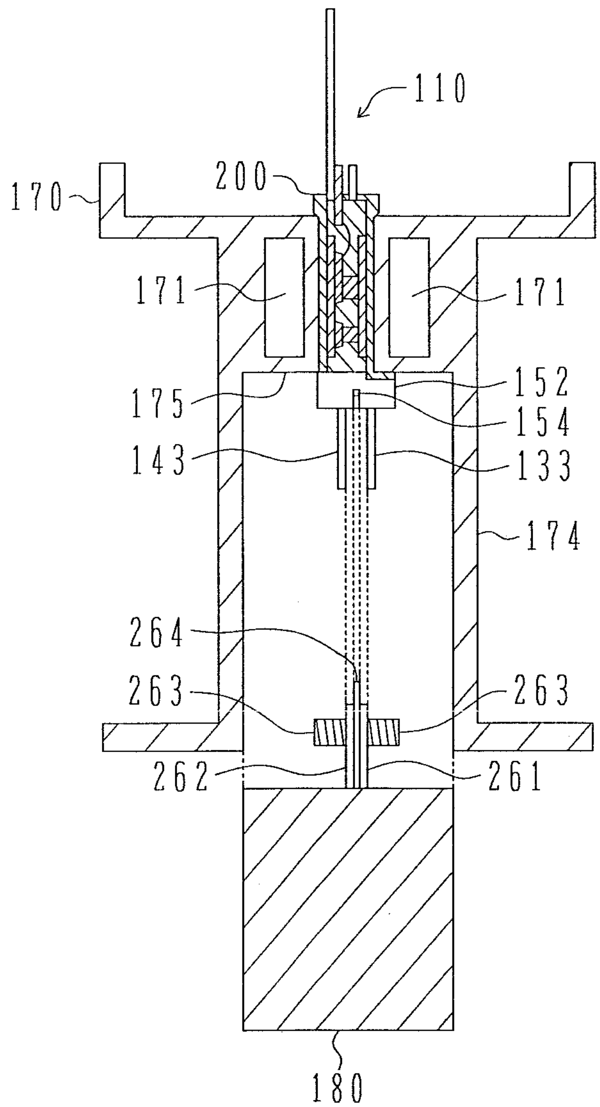
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FIG. 33

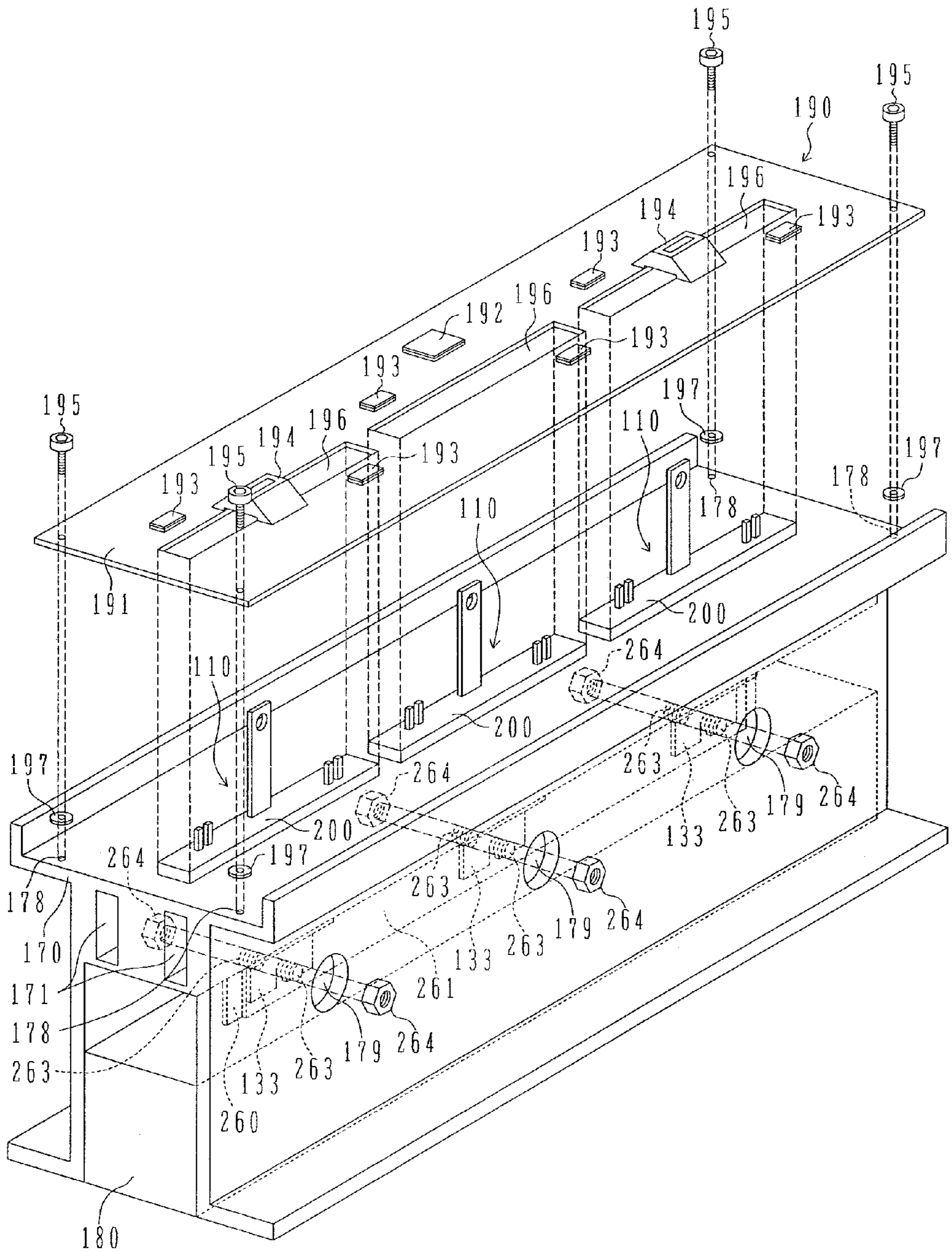

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FIG. 34

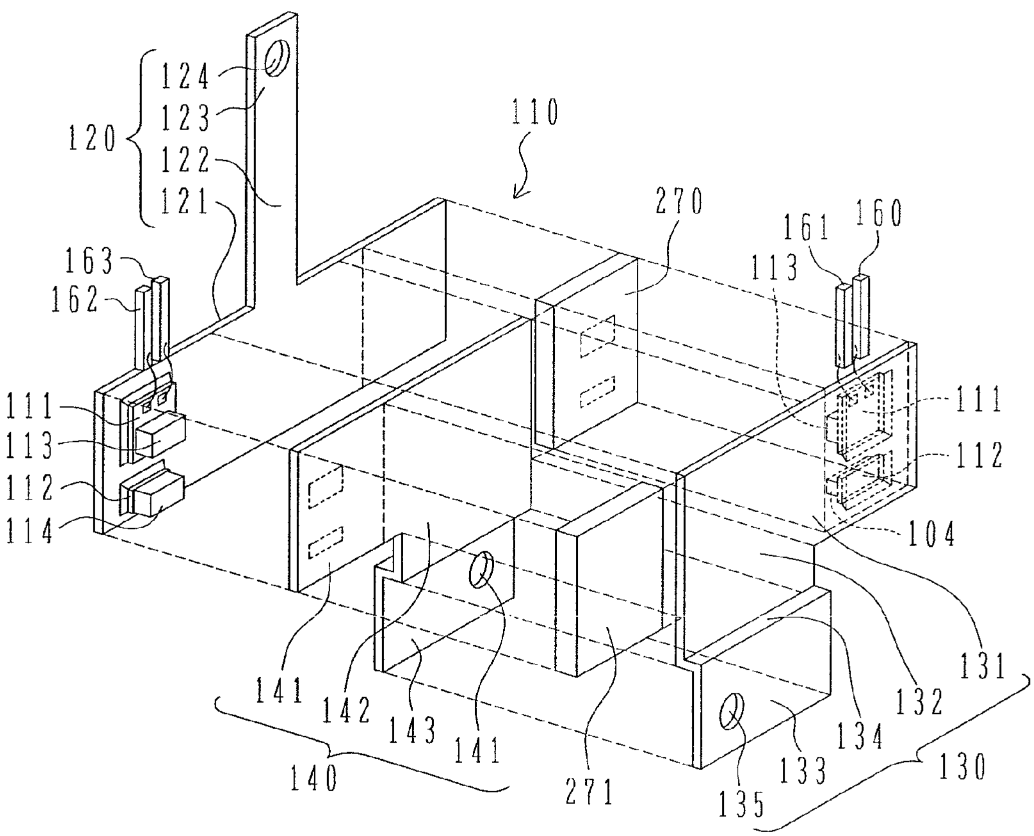
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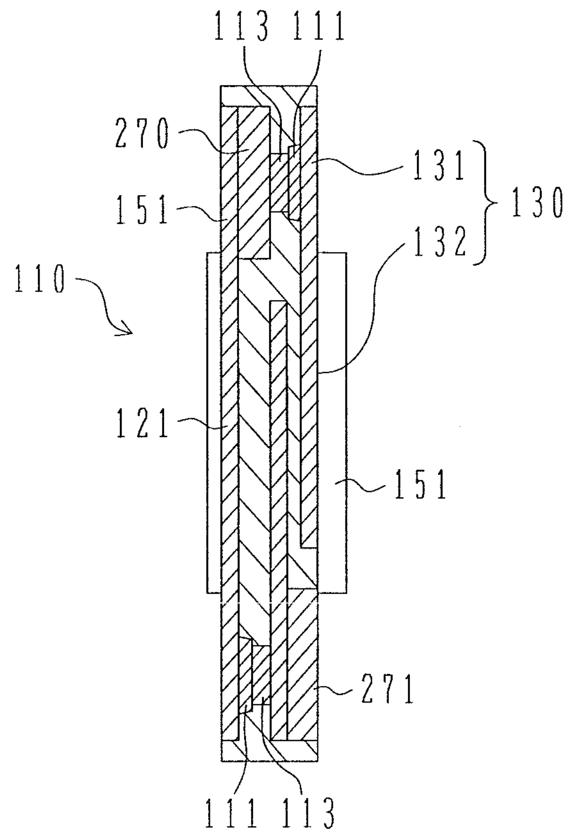
FIG. 35



ELECTRIC CIRCUIT DEVICE, ELECTRIC CIRCUIT MODULE, AND POWER CONVERTER

RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/241,600, filed Sep. 23, 2011, the disclosure of which is incorporated herein in its entirety and the priority of which is claimed under 35 U.S.C. §120, which is a continuation of U.S. patent application Ser. No. 12/715,025, filed Mar. 1, 2010, now U.S. Pat. No. 8,081,472, the disclosure of which is incorporated herein in its entirety and the priority of which is claimed under 35 U.S.C. §120, which, in turn, is a continuation of U.S. patent application Ser. No. 11/740,622, filed Apr. 26, 2007, now U.S. Pat. No. 7,961,472, the priority of which is claimed under 35 U.S.C. §120 and the disclosure of which is incorporated herein in its entirety, which, in turn, claims the benefit of priority under 35 U.S.C. §119 to Japanese patent application serial no. 2006-123835, filed Apr. 27, 2006, the disclosure of which is incorporated herein in its entirety, the priority of which is also claimed in the present application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an electric circuit device adapted to configure an electric circuit that uses semiconductors, an electric circuit module with the device mounted therein, and an electric power converter having the module.

2. Description of the Related Art

Known techniques related to an electric circuit device adapted to configure an electric circuit that uses semiconductors, an electric circuit module having the device mounted therein, and an electric power converter having the module, are described in JP-A-2004-208411, JP-A-2004-193476, and JP-A-10-248266, for example. JP-A-2004-208411 discloses the technique for sandwiching high-side semiconductor chips (IGBT chip and diode chip) and low-side semiconductor chips (IGBT chip and diode chip) by use of a common middle-side plate and high-side plate and a common middle-side plate and low-side plate, respectively, and cooling each of the semiconductor chips from both sides.

Also, JP-A-2004-193476 discloses the technique for arranging an IGBT element and a diode element between a P-side electrode, a middle electrode, and an N-side electrode, and stacking these elements in a longitudinal direction for reduced line inductance.

Additionally, JP-A-10-248266 discloses the technique for arranging a semiconductor module and a smoothing capacitor vertically, electrically connecting these elements via two pairs of connection conductors that are a stacked structure of thin plates each fastened at one end to the terminal sections of the module and the capacitor, connected at the other end to each other with the same polarity, and formed with an insulating member sandwiched between heteropolar conductors, and shortening a line distance between the module and the capacitor in order to reduce line inductance therebetween.

SUMMARY OF THE INVENTION

In recent years, development of electric driving has been accelerated in various industries. In automobiles, for example, electric driving in various systems for installation in the vehicle, including a vehicular driving system, is increasing in terms of improvement of the vehicle in fuel efficiency

and protection of the global environment. Further acceleration of such electric driving is recently desired. To electrically drive a vehicle-mounted system, however, it becomes necessary to add an electric machine that drives a mechanism to be driven, and an electric power converter that controls driving of a rotary electric machine by controlling the electric power supplied from a vehicle-mounted power supply to the rotary electric machine, as well as to adopt substitutes for the conventional system components. For further accelerated electric driving of the vehicle-mounted system, therefore, the electric machine and its controller require further improvement in mountability and further reduction in price.

The electric machine and the electric power converter must be further miniaturized to implement their further improvement in mountability and their further reduction in price. One possible method of achieving further miniaturization of the power converter is to construct an electric circuit device by use of smaller semiconductor chips to form a power conversion circuit and then mount the electric circuit device in a more compact electric circuit module. However, semiconductor chips generate a large amount of heat during an electrical conducting state, and as the chips are dimensionally reduced, they correspondingly increase in heat capacity and hence in the amount of heat generated. The amount of heat generated by the semiconductor chips is also increased by the internal line inductance of the electric circuit device and by electrical loss due to the line inductance occurring at the input side of the electric circuit device during operation. Accordingly, further improvement of the electric circuit device in cooling performance and further reduction of the operating loss due to the line inductance become important technical factors in miniaturizing the power converter.

In particular, to miniaturize the power converter exposed to a severe operating/mounting environment, for example, to miniaturize the power converter used in the driving system of an automobile, it is absolutely necessary to simultaneously realize further improvement of the electric circuit device in cooling performance and further reduction of the operating loss due to the line inductance.

In this context, as disclosed in the three JP-A publications, the effectiveness of the conventional techniques is confined only to either the improvement of the electric circuit device in terms of cooling performance or the reduction of the operating loss due to the line inductance. At present, therefore, the conventional techniques are not as effective as they can attain both of the above two factors.

The present invention typically provides an electric circuit device that can attain improvement of its cooling performance and reduction of its operating loss due to line inductance.

In the electric circuit device of the present invention, a plurality of plate-shaped conductors electrically connected to a plurality of semiconductor chips are typically constructed so that each plate-shaped conductor is thermally connected to both sides of each semiconductor chip in order to make it possible to release heat from both chip surfaces of each semiconductor chip via the plate-shaped conductor. The plate-shaped conductors are also typically constructed so that among the multiple plate-shaped conductors, only a plate-shaped conductor for DC positive polarity and a plate-shaped conductor for DC negative polarity are opposed to each other at respective conductor surface.

According to the present invention having the above features, heat generated by each semiconductor chip can be released to the outside of the device via the plate-shaped conductors thermally connected to both sides of the semiconductor chip, so the semiconductor chip itself can be cooled from both sides thereof. In addition, according to the present invention, when currents of equal magnitude flow into the plate-shaped conductor for DC positive polarity and the plate-shaped conductor for DC negative polarity, directions of the currents can be changed to opposite directions at opposed sections of the two plate-shaped conductors. Thus, a magnetic field generated by the current flowing through the plate-shaped conductor for DC positive polarity can be offset by a magnetic field generated by the current flowing through the plate-shaped conductor for DC negative polarity. Hence, according to the present invention, the line inductance occurring in the electric circuit device can be reduced and this, in turn, makes it possible to reduce the operating loss of the semiconductor due to line inductance. According to the present invention, therefore, the improvement of cooling performance and the reduction of the operating loss due to the line inductance can be realized at the same time.

The present invention also provides an electric circuit module that uses an electrical insulating structure to mount the above electric circuit device on a heat release structure having a surface cooled by a cooling medium.

In addition, the present invention provides an electric power converter that includes the above electric circuit module, a controller for controlling an operational state of the electric circuit module, and a capacitor device electrically connected to an electric power conversion circuit composed of the electric circuit module.

According to the present invention summarized above, since the improvement of cooling performance and the reduction of the operating loss due to line inductance can be realized at the same time, a more compact electric circuit device can be constructed using smaller semiconductor chips.

According to the present invention, since the above electric circuit device is mounted, it is also possible to construct a more compact electric circuit module.

In addition, according to the present invention, since the above electric circuit module is mounted, it is possible to construct a more compact electric power converter and thus to contribute to improving the power converter in mountability and reducing a price of the power converter. The present invention yields advantageous effects particularly significant in the power converter mounted in an automobile.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exploded perspective view showing an internal configuration of an electric circuit device according to a first embodiment of the present invention;

FIG. **2** is an assembly perspective view of FIG. **1**;

FIG. **3** is a perspective view showing an external configuration of the electric circuit device according to the first embodiment of the present invention;

FIG. **4** is a cross-sectional view taken along the line A-A' of FIG. **3**;

FIG. **5** is a cross-sectional view taken along the line A-B' of FIG. **3**;

FIG. **6** is a circuit diagram that shows advantageous effects of the electric circuit device according to the first embodiment of the present invention;

FIG. **7** is a perspective view that shows advantageous effects of the electric circuit device according to the first embodiment of the present invention;

FIG. **8** is a perspective view showing an inverter configuration according to the first embodiment of the present invention;

FIG. **9** is a cross-sectional view taken along the line A-A' of FIG. **8**;

FIG. **10** is an exploded perspective view of FIG. **8**;

FIG. **11** is a cross-sectional view taken along the line A-A' of FIG. **10**;

FIG. **12** is another exploded perspective view of FIG. **8**;

FIG. **13** is a cross-sectional view taken along the line A-A' of FIG. **12**;

FIG. **14** is a plan view showing a configuration of a heat release base used in the inverter of FIG. **8**;

FIG. **15** is a perspective view showing a configuration of a connection member used in the inverter of FIG. **8**;

FIG. **16** is a side view showing the configuration of the connection member used in the inverter of FIG. **8**;

FIG. **17** is a top view showing the configuration of the connection member used in the inverter of FIG. **8**;

FIG. **18** is a cross-sectional view showing the configuration of the connection member used in the inverter of FIG. **8**;

FIG. **19** is a circuit diagram showing a circuit configuration of the inverter according to the first embodiment of the present invention;

FIG. **20** is a block diagram showing a hybrid automobile configuration according to the first embodiment of the present invention;

FIG. **21** is a perspective view showing a configuration of an electric circuit device according to a second embodiment of the present invention;

FIG. **22** is a perspective view showing a configuration of an electric circuit device according to a third embodiment of the present invention;

FIG. **23** is a perspective view showing a configuration of an electric circuit device according to a fourth embodiment of the present invention;

FIG. **24** is a perspective view showing a configuration of an inverter according to a fifth embodiment of the present invention;

FIG. **25** is an exploded perspective view of FIG. **24**;

FIG. **26** is an exploded perspective view showing a configuration of an integrated terminal used in the inverter of FIG. **24**;

FIG. **27** is a perspective view showing a configuration of an inverter according to a sixth embodiment of the present invention;

FIG. **28** is an exploded view of FIG. **27**;

FIG. **29** is an exploded perspective view showing a configuration of an electric circuit device according to a seventh embodiment of the present invention;

FIG. **30** is a perspective view showing an external configuration of the electric circuit device according to the seventh embodiment of the present invention;

FIG. **31** is an exploded perspective view showing an inverter configuration according to the seventh embodiment of the present invention;

FIG. **32** is a cross-sectional view taken along the line A-A' of FIG. **31**;

FIG. **33** is an exploded perspective view showing another configuration of the electric circuit device according to the seventh embodiment of the present invention;

FIG. **34** is an exploded perspective view showing a configuration of an electric circuit device according to an eighth embodiment of the present invention; and

FIG. **35** is a cross-sectional view showing the configuration of the electric circuit device according to the eighth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be described hereunder in accordance with the accompanying drawings.

Examples of applying the present invention to a vehicular electric power converter of a vehicular electric machine system mounted in an automobile, and more particularly, to a vehicular driving inverter used in a vehicular electric machine system and exposed to very severe environments such as a mounting environment and an operating environment, will be described hereunder as the embodiments below. The vehicular electric power inverter disposed in an vehicular electric machine system as a controller to control driving of a vehicular driving motor transforms DC power supplied from a vehicle-mounted battery or vehicle-mounted power generator constituting a vehicle-mounted power supply, into required AC power and then supplies the AC power to the vehicular driving motor to control the driving thereof.

The configuration described below can also be applied to inverters constructed for purposes other than vehicle driving, for example, an inverter used as a controller of an electric braking device or electric power steering device. In addition, the configuration below can be applied to DC-DC power converters such as a DC-DC converter and a DC chopper, to AC-DC power converters, or to other vehicular power converters. Furthermore, the configuration below can be applied to industrial power converters used as controllers of motors which drive factory equipment, or to household power converters used in controllers of motors which drive household solar light power-generating systems or electrical household appliances. For improved mountability and reduced price of an electric power converter, application to a more compact converter, in particular, is preferable.

Also, the embodiments below will be described hereunder taking an example in which a vehicular driving electric machine system with a vehicular driving inverter applying the present invention is mounted in a hybrid automobile that employs an internal-combustion engine and a vehicular driving motor as driving sources of a vehicle and is constructed so as to drive either one of two pairs of front or rear wheels of the vehicle. Some kinds of hybrid automobiles use an engine to drive either one of two pairs of front or rear wheels and a vehicular driving motor to drive the other pair of front or rear wheels. The vehicular driving electric machine system in any one of the embodiments can also be applied to the hybrid automobile constructed in that way.

The vehicular driving electric machine system can be further applied to a pure electric automobile constructed so as to drive either front or rear wheels by using a vehicular driving motor as a driving source of the vehicle. Furthermore, the vehicular electric machine system with the vehicular inverter applying the present invention can be applied to a simplified hybrid automobile adapted to use an internal-combustion engine as a driving source of the vehicle to drive either the front or rear wheels and use the vehicular electric machine system to start the engine or to provide engine power assistance for the engine start and for accelerated engine operation. Moreover, the vehicular electric machine system with the vehicular inverter applying the present invention can be applied to an automobile adapted to use an internal-combustion engine as a driving source of the vehicle to drive either the front or rear wheels and to have a vehicle-mounted electric machine system such as an electric braking device and an electric power steering device.

First Embodiment

Hereunder, a first embodiment of the present invention will be described in accordance with FIGS. **1** to **20**.

First, a configuration of a hybrid electric automobile **1** is described below using FIG. **20**.

The hybrid electric automobile (hereinafter, referred to as HEV) **1** of the present embodiment is one electric vehicle and has two vehicular driving systems. One of them is an engine system that uses an internal-combustion engine **10** as a motive power source. The engine system is used as a driving source of the HEV. The other is a vehicular electric machine system that use motor generators **30**, **40** as motive power sources. The vehicular electric machine system is primarily used as another driving source of the HEV and as an electric power generator for the HEV.

At a front section of a vehicle body (not shown), front wheel axles **3** are axially supported so as to be rotatable. One pair of front wheels **2** are disposed at both ends of each front wheel axle **3**. At a rear section of the vehicle body, rear wheel axles (not shown) are axially supported so as to be rotatable. One pair of rear wheels (not shown) are disposed at both ends of each rear wheel axle. The HEV of the present embodiment employs a so-called front wheel drive scheme. In this scheme, the front wheels **2** operate as main wheels driven by motive power, and the rear wheels operate as trailing wheels simultaneously rotated by movements of the front wheels **2**. The HEV, however, may employ the inverse of the above, that is, a rear wheel drive scheme.

A front wheel differential gear **4** (hereinafter, referred to as a front wheel DEF) is provided centrally between the front wheel axles **3**. The front wheel axles **3** are mechanically connected to an output side of the front wheel DEF **4**. A transmission **20** is mechanically connected at its output shaft to an input side of the front wheel DEF **4**. The front wheel DEF **4** is a differential motive power distributor that distributes rotational driving force to the left and right front wheel axles **3** after the rotational driving force has been transmitted from the transmission **20** as a result of a gearshift thereby. The motor generator **30** is mechanically connected at its output side to an input side of the transmission **20**. The engine **10** and the motor generator **40** are mechanically connected at respective output sides to an input side of the motor generator **30** via the motive power distributor **50**.

The motor generators **30**, **40** and the motive power distributor **50** are stored within an enclosure of the transmission **20**.

The motive power distributor **50** is a differential mechanism constituted by gears **51** to **58**. The gears **53** to **56** are bevel gears. The gears **51**, **52**, **57**, **58** are spur gears. Motive power of the motor generator **30** is transmitted directly to the transmission **20**. A shaft of the motor generator **30** is coaxial with the gear **57**. In this configuration, when electric power for driving is not supplied to the motor generator **30**, motive power that has been transmitted to the gear **57** is further transmitted intact to the input side of the transmission **20**. When the gear **51** is driven by operation of the engine **10**, motive power of the engine **10** is transmitted from the gear **51** to the gear **52**, then from the gear **52** to the gears **54** and **56**, and from the gears **54** and **56** to the gear **58**. Finally, the power is transmitted to the gear **57**. When the gear **53** is driven by operation of the motor generator **40**, rotation of the motor generator **40** is transmitted first from the gear **53** to the gears **54** and **56**, and then from the gears **54** and **56** to the gear **58**. Finally, the rotation is transmitted to the gear **57**.

Instead of the above differential mechanism, an epicyclic gear train or any other appropriate mechanism may be used as the motive power distributor **50**.

The motor generator **30** (**40**) is a synchronous machine having a permanent magnet in a rotor section.

Alternating-current power supplied to an armature winding assembly **31** (**41**) of a stator is controlled by an inverter **100** (**300**), whereby driving is controlled. A battery **60** is electrically connected to the inverter **100** (**300**), and electric power can be exchanged reciprocally between the battery **60** and the inverter **100** (**300**).

The present embodiment includes a first motor electric power generator unit consisting essentially of the motor generator **30** and the inverter **100**, and a second motor electric power generator unit consisting essentially of the motor generator **40** and the inverter **300**, and either of the two motor electric power generator units is selectively used according to a particular operating state. That is to say, for vehicle drive torque assistance during vehicle driving by the motive power transmitted from the engine **10**, the second motor electric power generator unit is activated as an electric power generator unit to generate electric power using the motive power of the engine **10**, and the electric power that has thus been obtained operates the first motor electric power generator unit as an electric driving unit. In addition, for vehicle speed assistance in a case similar to the above, the first motor electric power generator unit is activated as an electric power generator unit to generate electric power using the motive power of the engine **10**, and the electric power that has thus been obtained operates the second motor electric power generator unit as the electric driving unit.

Additionally, in the present embodiment, operating the first motor electric power generator unit as the electric driving unit by the power of the battery **60** makes the vehicle drivable only by the motive power of the motor generator **30**.

Furthermore, in the present embodiment, the battery **60** can be recharged using electric power generated by operating the first motor electric power generator unit or the second motor electric power generator unit as the electric power generator unit by use of the motive power of the engine **10** or the motive power transmitted from the wheels.

Next, electric circuit configurations of the inverters **100**, **300** will be described hereunder using FIG. **19**.

While the present embodiment is described below using an example of constructing the inverters **100**, **300** independently, the inverters **100**, **300** may be integrated to construct one inverter unit.

In addition, in the present embodiment, an electric power system and a signal system are shown with a solid line and a dotted line, respectively, to make the electric power system and the signal system readily distinguishable.

The inverter **100** (**300**) includes a semiconductor module **101**, a capacitor **102**, and a controller **103**.

The semiconductor module **101** constitutes a main circuit for electric power conversion and has a plurality of switching power semiconductor elements. The plurality of switching power semiconductor elements operate under a driving signal output from the controller **103**, and convert the DC power supplied from the battery **60**, into three-phase AC power. The thus-converted power is supplied to the armature winding assembly **31** (**41**) of the motor generator **30** (**40**). The main circuit for electric power conversion is composed of a three-phase bridge circuit, and series circuits for three phases are each formed by electrical connection between a positive side and negative side of the battery **60**. The series circuits are also called arms, which are constructed of the switching power semiconductor element for an upper arm and the switching power semiconductor element for a lower arm.

The present embodiment uses insulated gate bipolar transistors (IGBTs) **111** as the switching power semiconductor elements. Each IGBT **111** has a collector electrode, an emitter electrode, and a gate electrode. A diode **112** is electrically connected between the collector electrode and emitter electrode of the IGBT **111**. The diode **112** has a cathodic electrode and an anodic electrode, and the cathodic electrode and the anodic electrode are electrically connected to the collector electrode and emitter electrode, respectively, of the IGBT **111** so that a direction in which a current flows from the emitter electrode of the IGBT **111** towards the collector electrode thereof becomes a forward direction.

Metal-oxide semiconductor field effect transistors (MOSFETs) may be used as the switching power semiconductor elements. Each MOSFET has a drain electrode, a source electrode, and a gate electrode.

Between its source electrode and its drain electrode, the MOSFET includes a parasitic diode adapted so that a direction in which a current flows from the drain electrode towards the source electrode becomes a forward direction. Accordingly, unlike an IGBT, there is no need to provide an independent diode.

Arms for three phases are provided in association with phase windings of the armature winding assembly **31** (**41**) in the motor generator **30** (**40**). The source electrode of the IGBT **111** and the drain electrode thereof are electrically interconnected in series via an intermediate electrode **120**, whereby each of the arms is constructed. The drain electrode of the IGBT **111** in the upper arm of the arms is electrically connected to a positive-polarity capacitor electrode **171** of the capacitor device **102** via a positive-polarity electrode **130**, and the source electrode of the IGBT **111** in the lower arm of the three arms is electrically connected to a negative-polarity capacitor electrode **172** of the capacitor device **102** via a negative-polarity electrode **140**. The intermediate electrode **120** equivalent to a midpoint section between the three arms (i.e., a connection between the source electrode of the IGBT **111** in the upper arm and the drain electrode of the IGBT **111** in the lower arm) is electrically connected to the appropriate phase winding of the armature winding assembly **31** (**41**) in the motor generator **30** (**40**). In the present embodiment, as will be detailed later herein, one arm is constructed using one electric circuit device (semiconductor device) **110**.

The capacitor device **102** constitutes a smoothing circuit that suppresses changes in DC voltage due to switching operation of the IGBT **111**. A positive-polarity side and negative-polarity side of the battery **60** are electrically connected to the positive-polarity capacitor electrode **171** and negative-polarity capacitor electrode **171** of the capacitor device **102**, respectively. Thus, between a DC side (input side) of the semiconductor module **101** and the battery **60**, the capacitor device **102** is electrically connected in parallel to both the DC side of the semiconductor module **101** (i.e., between the respective positive-polarity electrodes **130** and negative-polarity electrodes **140** of the three arms) and the battery **60**.

The controller **103** for operating the IGBT **111** includes a control unit that uses input information from other controllers or sensors or other elements to create a timing signal in order to control switching timing of the IGBT **111**, and a driver that uses an output timing signal from the control unit to create a driving signal required for the IGBT **111** to perform switching operation.

The control unit is constituted by a microcomputer. A target torque value requested to the motor generator **30** (**40**), a value of the electric current supplied from the semiconductor module **101** to the armature winding assembly **31** (**41**) of the motor generator **30** (**40**), and a magnetic pole position of the rotor of the motor generator **30** (**40**) are input as input information to the microcomputer. The target torque value is based on a command signal that has been output from a host controller. The electric current value is a result of detection based on a detection signal output from a current sensor **194**. The magnetic pole position is a result of detection based on a detection signal output from a rotor magnetic pole sensor **32**

(**42**) provided in the motor generator **30** (**40**). An example of detecting two phases of current data is described below in connection with the present embodiment. However, three phases of current data may be detected instead.

The microcomputer uses the above target torque value to compute electric current command data on a d-axis and a q-axis, uses differentials between computed electric current command data of the d-axis and q-axis and detected electric current command data of the d-axis and q-axis to compute voltage command data on the d-axis and the q-axis, and uses a detected magnetic pole position to convert computed voltage command data of the d-axis and q-axis into voltage command data of each phase (U, V, W). Also, the microcomputer create a pulse-like modulated wave by comparing a fundamental wave (sine wave) and a carrier wave (triangular wave) based on the voltage command data of the U-phase, V-phase, and W-phase, and outputs the modulated wave as a PWM (Pulse Width Modulated) signal to the driver. Six PWM signals, one for the upper or lower arm of each phase, are output from the microcomputer to the driver. Timing signals output from the microcomputer may be other signals such as rectangular wave signals.

The driver is constituted by an integrated circuit, or an IC that is an integrated set of multiple electronic circuit components. While the present embodiment is described below taking a one-in-one scheme as an example of providing one IC for the upper or lower arm of each phase, the present invention may employ any other scheme such as a two-in-one scheme with one IC provided for the upper and lower arms of each phase, or a six-in-one scheme with one IC provided for all arms. To drive the lower arm, the driver amplifies an associated PWM signal and outputs the PWM signal as a driving signal to the gate electrode of the IGBT **111** of the lower arm. To drive the upper arm, the driver shifts a reference potential level of an associated PWM signal to a reference potential level of the upper arm before amplifying the PWM signal, and then outputs the PWM signal as a driving signal to the gate electrode of the IGBT **111** of the upper arm. Thus, each IGBT **111** performs the switching operation in accordance with the input driving signal.

The controller **103** also detects abnormal states (overcurrent, overvoltage, overtemperature, and the like), thus protecting the semiconductor module **101**. For this purpose, sensing information is input to the controller **103**. For example, information on the current flowing through the source electrode of each IGBT **111** is input from a sensor lead wire **163** of each arm to the associated driver (IC). Accordingly, the driver (IC) conducts overcurrent detection and if an overcurrent is detected, the driver (IC) stops the switching operation of the associated IGBT **111** and protects the associated IGBT **111** from the overcurrent. Temperature information on the semiconductor module **101** is input from a temperature sensor **104** provided in/on the semiconductor module **101**, to the microcomputer. Voltage information on the DC positive-polarity side of the semiconductor module **101** is also input to the microcomputer. The microcomputer conducts overtemperature and overvoltage detection based on those kinds of information, and if an overtemperature or an overvoltage is detected, the microcomputer stops the switching operation of all IGBTs **111** and protects the semiconductor module **101** from the overtemperature or the overvoltage.

Next, actual configurations of the inverters **100**, **300** for realizing the electric circuit configuration of FIG. **19** will be described hereunder using FIGS. **1** to **18**.

Under the conventional techniques, multiple semiconductor chips are mounted on the heat-releasing base of a module casing via an electrically insulated circuit board, then wiring is conducted using wiring members such as wires, and a semiconductor module is constructed. In the present embodiment, however, semiconductor chips and wiring members are constructed as components or devices beforehand in a separated state with respect to the semiconductor module. Thus, a so-called discrete component construction or device construction is realized and the semiconductor module is constructed by building the discrete components or the devices into the semiconductor module during manufacture thereof.

First, a configuration of the electric circuit device (semiconductor device) **110**, one of the above discrete components or devices, will be described hereunder using FIGS. **1** to **5**.

In the present embodiment, as described above, the arms are constructed as discrete components or devices in two-in-one units.

The electric circuit device **110** is, in appearance, a structure formed as follows. First, three kinds of elements (namely, the semiconductor chips constituting an IGBT **111** and a diode **112**, metallic buffering members **113**, **114**, and portions of multiple electrodes and multiple wires) are first embedded in a molded body **150** constructed by transfer-molding a sealing resin (epoxy resin) that is a packaging material. Next, other portions of the multiple electrodes and multiple wires are either extended outward from the inside of the molded body **150** to the outside thereof, or exposed outside the molded body **150**.

The electric circuit device **110** has the intermediate electrode **120**, the positive-polarity electrode **130**, and the negative-polarity electrode **140**, as the above multiple electrodes. The intermediate electrode **120**, the positive-polarity electrode **130**, and the negative-polarity electrode **140** are each formed using a flat-plate conductor made of a metal, for example, a copper alloy or copper excellent in thermal conductivity and in electrical conductivity. The electric circuit device **110** has the foregoing gate lead wires **160**, **162** and sensor lead wires **161**, **163**, as the above multiple wires. The gate lead wires **160**, **162** and the sensor lead wires **161**, **163** are each formed using an elongated rod-like or pin-shaped prismatic conductor made of a metal, for example, a copper alloy or copper excellent in thermal conductivity and in electrical conductivity.

In the present embodiment, the intermediate electrode **120**, the positive-polarity electrode **130**, and the negative-polarity electrode **140** are constructed so that the semiconductor chips inside the electric circuit device **110** can be improved in heat release characteristics and reduced in line inductance at the same time.

In the present embodiment, the intermediate electrode **120** is hereinafter referred to simply as the M-electrode **120**, the positive-polarity electrode **130** as the P-electrode **130**, and the negative-polarity electrode **140** as the N-electrode **140**, the gate lead wires **160**, **162** as the G-wires **160**, **162**, and the sensor lead wires **161**, **163** as the S-wires **161**, **163**.

Additionally, in the present embodiment, in a rectangular parallelepide or square plate body, one pair of rectangular opposed planes larger in surface area than other planes are defined as principal planes. Also, four rectangular planes of the rectangular parallelepide or square plate body that extend along, and are formed at right angles to, four edges (four sides) of each such principal plane, and that have surface areas smaller than those of the principal planes, are defined as peripheral planes. In addition, one pair of longer sides of all four sides that constitute rectangular planes including the principal planes are defined as long sides, and one pair of shorter sides are defined as short sides. Furthermore, a direction in which the long sides of each rectangular plane including each principal plane extends is defined as a long-side direction or a longitudinal direction, and a direction in which the short sides of the rectangular plane including the principal plane extends is defined as a short-side direction or a lateral direction. Moreover, a distance between the principal planes is defined as thickness or height, and an opposite direction to each principal plane (i.e., a direction in which the long sides of each peripheral plane extends) is defined as a thickness direction or a height direction.

The molded body **150** is subdivided into two molded bodies: a first molded section **151** and a second molded section **152**.

The first molded section **151** is a rectangular parallelepide or square plate section formed to package semiconductor chip-mounting sections of the M-electrode **120**, P-electrode **130**, and N-electrode **140**, and to package portions of the G-wires **160**, **162**, and S-wires **161**, **163**. Length of the first molded section **151** is greater than plate thicknesses of the above electrodes or diameters of the above wires.

The second molded section **152** is formed centrally at one of lateral edges of the first molded section **151**. The second molded section **152** is a polyhedral solid section for packaging respective bends of the P-electrode **130** and N-electrode **140**, and is formed integrally with the first molded section **151**. The polyhedral solid constituting the second molded section **152** is a cutout formed by cutting off a portion of the rectangular parallelepide. That is to say, when the rectangular parallelepide is disposed so that one principal plane thereof faces the first molded section **151**, this principal plane facing the first molded section **151** is formed into a stepped shape and a concave-like groove **153** extending continuously in the long-side direction is formed centrally in the short-side direction of the other principal plane of the rectangular parallelepide. The portion of the second molded section **152** that extends in the same direction as that of the long sides of the first molded section **151** is dimensionally smaller than the long sides of the first molded section **151**. The portion of the second molded section **152** that extends in the same direction as thickness of the long sides of the first molded section **151** is dimensionally larger than thickness of the first molded section **151**. The second molded section **152** is formed with two steps. One of the two steps forms a connection region with respect to one lateral peripheral planes of the first molded section **151**, and is higher than the other step. That is to say, one step is an upper stage and the other step is a lower stage.

The concave-like groove **153** formed at a second short side of the second molded section **152** is formed so as to engage with a convex-like protrusion provided on a connecting member of the capacitor device **102** described on later pages herein. The concave-like groove **153** may be a convex-like protrusion, in which case, the convex-like protrusion provided on the connecting member of the capacitor device **102** is formed as a concave-like groove instead.

In the present embodiment, one principal plane (left side on the paper) of the first molded section **151** is hereinafter defined as a first principal plane, and the other principal plane (right side on the paper) as a second principal plane. Also, one lateral side (front side on the paper) of the first molded section **151** is defined as a first lateral side, and the other lateral side (rear side on the paper) as a second lateral side. In addition, one longitudinal side (upper side on the paper) is defined as a first longitudinal side, and the other longitudinal side (lower side on the paper) as a second longitudinal side. Furthermore, one side (left side on the paper) in the thickness direction of the first molded section **151** is defined as a first principal plane side, and the other side (right side on the paper) as a second principal plane side.

Inside the first molded section **151**, the M-electrode **120**, the G-wire **162**, and the S-wire **163** are arranged at the first principal side, and the P-electrode **130**, the N-electrode **140**, the G-wire **160**, and the S-wire **161** are arranged at the second principal side. Respective electrode surfaces of the M-electrode **120**, P-electrode **130**, N-electrode **140** are arranged in parallel to one another. The four electrode surfaces are also maintained in a parallel arrangement relationship with respect to the first and second principal planes of the first molded section **151**.

The M-electrode **120** is constituted by a heat-releasing section **121**, a lead wire **122**, and a lead terminal **123**.

The heat-releasing section **121** constitutes a mounting circuit board and heat-releasing circuit board for semiconductor chips, and is a rectangular flat-plate section extending along, and in parallel to, the first principal plane of the first molded section **151**. Long sides of the heat-releasing section **121** extend in the same direction as that of the long sides of the first molded section **151**, and are shorter than the long sides of the first molded section **151**. Short sides of the heat-releasing section **121** extend in the same direction as that of the short sides of the first molded section **151**, and are shorter than the long sides of the first molded section **151**. A first principal plane of the heat-releasing section **121** is formed as a heat release plane. The heat release plane of the heat-releasing section **121** becomes exposed at the surface of the first principal plane of the first molded section **151** so as to be flush with the first principal plane thereof. A second principal plane of the heat-releasing section **121** is formed as a mounting surface.

The lead wire **122** constituting an output end of an arm is formed at a first longitudinal edge of the heat-releasing section **121**. The lead wire **122** is a rectangular flat-plate section bent at right angles to a first longitudinal side of the heat-releasing section **121** from a central portion of a first longitudinal peripheral plane thereof, then extending straightly, and further extended outward from the first longitudinal peripheral plane of the first molded section **151**. The lead wire **122** is disposed on the same plane as that of the heat-releasing section **121**, and is formed integrally therewith. Short sides of the lead wire **122** extend in the same direction as that of the long sides of the first molded section **151**, and are shorter than the short sides of the heat-releasing section **121**. Long sides of the lead wire **122** extend to a first longitudinal side thereof.

The lead terminal **123** constituting a connecting portion of the output end of the arm is formed at a first longitudinal edge of the lead wire **122**. The first longitudinal edge of the lead wire **122** further extends straightly to the first longitudinal side thereof in that state, whereby the lead terminal **123** is formed as a rectangular flat-plate section. The lead terminal **123** is disposed on the same plane as that of the lead wire **122**, and is formed integrally therewith. A principal plane (terminal surface) of the lead terminal **123** is formed with a circular screw hole **124** cut through in the thickness direction of the first molded section **151**.

The P-electrode **130** and the N-electrode **140** are arranged at a section opposed to a second principal plane side of the M-electrode **120**.

The N-electrode **140** is constituted by a heat-releasing section **141**, a lead wire **142**, a lead terminal **143**, a first bend **144**, and a second bend **145**.

The heat-releasing section **141** constitutes a mounting circuit board and heat-releasing circuit board for semiconductor chips, and is a rectangular flat-plate section extending along, and in parallel to, the second principal plane of the first molded section **151**. Short sides of the heat-releasing section **141** extend in the same direction as that of the long sides of the first molded section **151**, and are shorter than the long sides of the first molded section **151**. Long sides of the heat-releasing section **141** extend in the same direction as that of the short sides of the first molded section **151**, and are equal to the short sides of the first molded section **151** in terms of length. A second principal plane of the heat-releasing section **141** is formed as a heat release plane. The heat release plane of the heat-releasing section **141** becomes exposed at the surface of the second principal plane of the first molded section **151** so as to be flush with the second principal plane thereof. A first principal plane of the heat-releasing section **141** is formed as a mounting surface.

The first bend **144** that changes a conductor position is formed at a second lateral edge of the heat-releasing section **141**. The second lateral edge of the heat-releasing section **141** is bent intact at right angles to the M-electrode **120** and extends straightly thereto, whereby the first bend **144** is formed as a rectangular flat-plate section. The first bend **144** is formed integrally with the heat-releasing section **141**. Long sides of the first bend **144** extend in the same direction as that of the long sides of the heat-releasing section **141**, and are equal to the long sides thereof in terms of length. Short sides of the first bend **144** extend in a direction of the M-electrode **120**, and are shorter than the short sides of the lead wire **122**.

The lead wire **142** constituting a high-potential input end of the arm is formed at an edge of a first principal plane of the first bend **144**. The edge of the first principal plane of the first bend **144** is bent intact at right angles to a second lateral edge thereof, then after extending straightly along, and in parallel to, the mounting plane of the heat-releasing section **121**, further bent at right angles to a second longitudinal edge of the first bend **144**, and extending straightly in parallel with respect to the mounting plane of the heat-releasing section **121**. The lead wire **142** is thus formed as an L-shaped flat-plate section. The lead wire **142** is disposed on a plane different from that of the heat-releasing section **121**, and is formed integrally with the first bend **144**. In this fashion, a position of the lead wire **142** is changed by the first bend **144**, and is closer to the M-electrode **120** than to the heat-releasing section **121**.

Of two edges of the L-shaped flat-plate conductor constituting the lead wire **142**, the edge opposite to that facing the first bend **144** (i.e., the edge extending towards the second longitudinal side) is formed with the second bend **145** that changes the conductor position. The side edge of the second bend **145** that extends towards the second longitudinal side of the lead wire **142** is bent intact at right angles to the M-electrode **120** and extends straightly thereto, whereby the second bend **145** is formed as a rectangular flat-plate section. The second bend **145** is formed integrally with the lead wire **142**. Long sides of the second bend **145** extend in the same direction as that of a side of the side edge extending towards the second longitudinal side of the lead wire **142**, and have a length equal to that of the side of the side edge extending towards the second longitudinal side of the lead wire **142**. Short sides of the second bend **145** extend in the direction of the M-electrode **120**, and are shorter than the short sides of the lead wire **122**.

The lead terminal **143** constituting a connecting portion of another output end of the arm is formed at an edge of a first principal plane of the second bend **145**. The first principal plane side edge of the second bend **145** is bent intact at right angles to the second longitudinal side, then extends straightly in parallel with respect to the mounting plane of the heat-releasing section **121**, and further extends outward from the second longitudinal side edge of the second molded section **152**. The lead terminal **143** is thus formed as a rectangular flat-plate section. The lead terminal **143** is disposed on a plane different from those of the heat-releasing section **141** and lead wire **142** (that is, the lead terminal **143** is disposed on the same plane as that of the heat-releasing section **121**, directly under the second longitudinal side thereof). The lead terminal **143** is formed integrally with the second bend **145**. In this fashion, a position of the lead terminal **143** is changed by the second bend **145**, and is closer to the M-electrode **120** than to the heat-releasing section **141** and the lead wire **142**. Short sides of the lead terminal **143** extend in the same direction as that of the long sides of the heat-releasing section **141**, and are shorter than the long sides thereof. Long sides of the lead terminal **143** extend in the same direction as that of the long sides of the second bend **145**, and equal to the long sides thereof in terms of length. A circular screw hole **146** extending through in the thickness direction of the first molded section **151** is formed at a second lateral side edge of a principal plane (terminal surface) of the lead terminal **143**.

The P-electrode **130** is constituted by a heat-releasing section **131**, a lead wire **132**, a lead terminal **133**, and a bend **134**.

The heat-releasing section **131** constitutes a mounting circuit board and heat-releasing circuit board for semiconductor chips, and is a rectangular flat-plate section extending along, and in parallel to, the second principal plane of the first molded section **151**. Short sides of the heat-releasing section **131** extend in the same direction as that of the long sides of the first molded section **151**, and are shorter than the long sides of the first molded section **151**. Long sides of the heat-releasing section **131** extend in the same direction as that of the short sides of the first molded section **151**, and are equal to the short sides of the first molded section **151** in length. A second principal plane of the heat-releasing section **131** forms a heat release plane. The heat release plane of the heat-releasing section **131** becomes exposed at the surface of the second principal plane of the first molded section **151** so as to be flush with the second principal plane thereof. A first principal plane of the heat-releasing section **131** forms a mounting surface.

The lead wire **132** constituting a low-potential input end of the arm is formed at a second lateral side edge of the heat-releasing section **131**. A first lateral side edge of the heat-releasing section **131** extends intact along the second principal plane of the lead wire **142**, in parallel to the second principal plane thereof, and further straightly towards the first lateral side. Additionally, the first lateral side edge of the heat-releasing section **131** is bent at right angles to the second longitudinal side and extends straightly along, and in parallel to, the second principal plane of the lead wire **142**. The lead wire **132** is thus formed as an L-shaped flat-plate section. The lead wire **132** is disposed on the same plane as that of the heat-releasing section **131**, and is formed integrally therewith. The second principal plane of the lead wire **142** constitutes a heat release plane of the semiconductor chip.

In the present embodiment, the second principal plane of the lead wire **132** is constructed as a heat release plane, and is exposed from the second principal plane of the first molded section **151**. However, this heat release plane may be covered with mold resin.

Of two edges of the L-shaped flat-plate conductor constituting the lead wire **132**, the edge opposite to that facing the heat-releasing section **131** (i.e., the edge extending towards the second longitudinal side) is formed with the bend **134** that changes the conductor position. The edge of the bend **134** that extends towards the second longitudinal side of the lead wire **132** is bent at right angles to the opposite side with respect to the M-electrode **120**, whereby the bend **134** is formed as a rectangular flat-plate section. The bend **134** is formed integrally with the lead wire **132**. Long sides of the bend **134** extend in the same direction as that of a side of the edge extending towards the second longitudinal side of the lead wire **132**, and have a length equal to that of the side of the edge extending towards the second longitudinal side of the lead wire **132**. Short sides of the bend **134** extend in the direction of the M-electrode **120**, and are shorter than the short sides of the lead wire **122**.

The lead terminal **133** constituting a connecting portion of a low-potential input end of the arm is formed at a side edge of a second principal plane of the bend **134**. The second principal plane side edge of the bend **134** is bent intact at right angles to the second longitudinal side, then extends straightly along, and in parallel to, the second principal plane of the heat-releasing section **143**, and further extends outward from the second longitudinal side edge of the second molded section **152**. The lead terminal **133** is thus formed as a rectangular flat-plate section. The lead terminal **133** is disposed on a plane different from those of the heat-releasing section **131** and lead wire **132** (that is, the lead terminal **143** is disposed externally to the second principal plane of the first molded section **151**). The lead terminal **133** is formed integrally with the bend **134**. In this fashion, a position of the lead terminal **133** is changed by the bend **134**, and is more distant from the M-electrode **120** than from the heat-releasing section **131** and the lead wire **132**. Short sides of the lead terminal **133** extend in the same direction as that of the long sides of the heat-releasing section **131**, and are shorter than the long sides of the heat-releasing section **141**. Long sides of the lead terminal **133** extend in the same direction as that of the long sides of the bend **134**, and equal to the long sides thereof in terms of length. A circular screw hole **135** extending through in the thickness direction of the first molded section **151** is formed at a first lateral side edge of a principal plane (terminal surface) of the lead terminal **133**.

Between the mounting surfaces of the heat-releasing sections **121** and **131**, semiconductor chips that constitute the upper-arm IGBT **111** and the upper-arm diode **112** are arranged next to each other in a longitudinal direction, and the semiconductor chips are mounted at the second lateral side edge.

In the present embodiment, the semiconductor chip constituting the upper-arm IGBT **111** is hereinafter referred to as the HI chip, and the semiconductor chip constituting the upper-arm diode **112**, as the HD chip.

For the HI chip disposed at the first longitudinal side, the chip surface that faces the second principal plane is solder-bonded to the mounting surface of the heat-releasing section **131** such that the collector electrode formed on the chip surface facing the second principal plane is electrically connected to the mounting surface of the heat-releasing section **131**. For the HD chip disposed at the second longitudinal side, the chip surface that faces the second principal plane is solder-bonded to the mounting surface of the heat-releasing section **131** such that the cathodic electrode formed on the chip surface facing the second principal plane is electrically connected to the mounting surface of the heat-releasing section **131**. A second principal plane of the buffering member **113** is solder-bonded to the chip surface of the HI chip at the first principal plane such that the emitter electrode and the buffering member **113** are electrically connected. A second principal plane of the buffering member **114** is solder-bonded to the chip surface of the HD chip at the first principal plane such that the anodic electrode and the buffering member **114** are electrically connected. First principal planes of the buffering members **113**, **114** are solder-bonded to the mounting surface of the heat-releasing section **121**. In this way, the HI chip and the HD chip are mounted in a stacked form between the mounting surfaces of the heat-releasing sections **121** and **131**.

Between the mounting surfaces of the heat-releasing sections **121** and **141**, semiconductor chips that constitute the lower-arm IGBT **111** and the lower-arm diode **112** are arranged next to each other in a longitudinal direction, and the semiconductor chips are mounted at the first lateral side edge.

In the present embodiment, the semiconductor chip constituting the lower-arm IGBT **111** is hereinafter referred to as the LI chip, and the semiconductor chip constituting the upper-arm diode **112**, as the LD chip.

For the LI chip disposed at the first longitudinal side, the chip surface that faces the first principal plane is solder-bonded to the mounting surface of the heat-releasing section **121** such that the collector electrode formed on the chip surface facing the first principal plane is electrically connected to the mounting surface of the heat-releasing section **121**. For the LD chip disposed at the second longitudinal side, the chip surface that faces the first principal plane is solder-bonded to the mounting surface of the heat-releasing section **121** such that the cathodic electrode formed on the chip surface facing the first principal plane is electrically connected to the mounting surface of the heat-releasing section **121**. The first principal plane of the buffering member **113** is solder-bonded to the chip surface of the LI chip at the second principal plane such that the emitter electrode and the buffering member **113** are electrically connected. The first principal plane of the buffering member **114** is solder-bonded to the chip surface of the LD chip at the second principal plane such that the anodic electrode and the buffering member **114** are electrically connected. The second principal planes of the buffering members **113**, **114** are solder-bonded to the mounting surface of the heat-releasing section **141**. In this way, the LI chip and the LD chip are mounted in a stacked form between the mounting surfaces of the heat-releasing sections **121** and **141**.

The buffering members **113**, **114** are spacers that are used for alleviating thermal stresses, for establishing electrical and thermal connection between the HI chip, the HD chip, and the heat-releasing section **121**, and for establishing electrical and thermal connection between the LI chip, the LD chip, and the heat-releasing section **141**. The spacers are block structures of a rectangular solid shape, both made of a thermally conductive and electrically conductive metal, for example, an alloy of molybdenum and copper.

An example of bonding the buffering member **113** to the HI and LI chip surfaces facing the emitter electrode, and bonding the buffering member **114** to the HD and LD chip surfaces facing the cathodic electrode, has been described in the present embodiment. However, the buffering members **113** and **114** may be bonded to the chip surfaces facing in opposite directions.

In addition, if the buffering member **113** bonded to the HI chip surface at the emitter electrode side is bonded to the HI chip surface at the collector electrode side instead and the buffering member **114** bonded to the HD chip surface at the anodic electrode side is bonded to the HD chip surface at the cathodic electrode side, cooling capabilities of the HI chip and HD chip at the heat-releasing section **121** of the M-electrode **120** and cooling capabilities of the LI chip and LD chip can be made to equal each other.

A gate electrode and a current detection electrode are formed on the chip surface of the HI chip at the first principal plane and on the chip surface of the LI chip at the second principal plane. A G-wire **160** and an S-wire **161** are electrically connected to the gate electrode and current detection electrode, respectively, of the HI chip by bonding an aluminum wire between both. A G-wire **162** and an S-wire **163** are electrically connected to the gate electrode and current detection electrode, respectively, of the LI chip by bonding an aluminum wire between both.

The G-wire **160** and the S-wire **161**, both juxtaposed in a long-side direction and arranged at the first longitudinal side of the second lateral side edge of the P-electrode **130**, extend towards the first longitudinal side and then further extend outward from the first longitudinal peripheral plane of the first molded section **151**. The G-wire **162** and the S-wire **163** juxtaposed in a long-side direction and arranged at the first longitudinal side of the first lateral side edge of the M-electrode **120**, extend towards the first longitudinal side and then further extend outward from the first longitudinal peripheral plane of the first molded section **151**.

When the electric circuit device **110** is assembled, the first principal plane-side chip surfaces of the LI chip and the LD chip are bonded to the mounting surface of the heat-releasing section **121** of the M-electrode **120** first. Next, the G-wire **162** is bonded to the gate electrode of the LI chip, and the S-wire **163**, to the current detection electrode of the LI chip. Also, the buffering member **113** is bonded to the chip surface of the LI chip that faces the second principal plane, and the buffering member **114**, to the chip surface of the LD chip that faces the second principal plane. A first assembly (see FIG. **1**) at the M-electrode **120** is now completed.

Next, the first assembly and the N-electrode **140** are opposed to each other and the mounting surface of the heat-releasing section **141** of the N-electrode **140** is bonded to the planes of the buffering members **113**, **114** that face the second principal plane. The N-electrode **140** is thus mounted in the first assembly so that the first principal plane of the lead wire **142** of the N-electrode **140** is as close as possible to the mounting surface of the heat-releasing section **121** of the M-electrode **120** via a clearance **117**. The clearance **117** has a magnitude which, when the clearance **117** is filled with an insulating member (mold resin), an electrical insulating distance can be obtained between the M-electrode **120** and the N-electrode **140**. The clearance **117** is determined by the length of the first bend **144** in the short-side direction thereof. A second assembly including the first assembly and the N-electrode **120** is now completed.

Next, the second principal plane-side chip surfaces of the HI chip and the HD chip are bonded to the mounting surface of the heat-releasing section **131** of the P-electrode **130**. Next, the G-wire **160** is bonded to the gate electrode of the HI chip, and the S-wire **161**, to the current detection electrode of the HI chip. Also, the buffering member **113** is bonded to the chip surface of the HI chip that faces the first principal plane, and the buffering member **114**, to the chip surface of the HD chip that faces the first principal plane. A third assembly (see FIG. **1**) at the P-electrode **130** is now completed. In the present embodiment, the third assembly is manufactured after the second assembly has been manufactured. However, the third assembly may be manufactured simultaneously with the first assembly, or after the first assembly has been manufactured, or before the second assembly is manufactured.

Next, the second assembly and the third assembly are opposed to each other and the mounting surface of the heat-releasing section **121** of the M-electrode **120** is bonded to the planes of the buffering members **113**, **114** that face the first principal plane. The third assembly is thus mounted in the second assembly so that the second principal plane of the lead wire **142** of the N-electrode **140** is closely opposed to the first principal plane of the heat-releasing section **132** of the P-electrode **130** via a clearance **118**. Also, the third assembly is mounted in the second assembly so that the first lateral side edge of the lead wire **132** is close to the second lateral side edge of the heat-releasing section **141** via a clearance **116**. Additionally, the third assembly is thus mounted in the second assembly so that the first principal plane of the lead terminal **133** is opposed to the second principal plane of the lead terminal **143** via a clearance **115**. The clearance **116** has a magnitude which, when the clearance **116** is filled with an insulating member (mold resin), an electrical insulating distance can be obtained between the P-electrode **130** and the N-electrode **140**. The clearance **116** is determined by the lengths of the heat-releasing section **131**, lead wire **132**, and heat-releasing section **141**, in the long-side directions of each. The clearance **118** has a magnitude which, when the clearance **118** is filled with an insulating member (mold resin), an electrical insulating distance can be obtained between the P-electrode **130** and the N-electrode **140**. The clearance **118** is determined by the length of the first bend **144** in the short-side direction thereof. The clearance **115** has a magnitude that makes it possible for a connection member of the later-described capacitor device **102** to be inserted (engaged) without a clearance. The clearance **115** is determined by the lengths of the bend **134** and second bend **145** in the thickness direction of the first molded section **151**. A fourth assembly including the second assembly and the third assembly is now completed (see FIG. **2**).

Next, the fourth assembly is fixed using a jig or a metallic mold. Next, heat and pressure are applied to a molded resin structure and then mold resin is poured into the jig or the metallic mold. Thus, a clearance between the fourth assembly and the jig or the metallic mold, and a clearance inside the fourth assembly are filled with the mold resin, whereby the molded body **150** shown in FIG. **3** is completed. In this case, the heat release plane of the heat-releasing section **121** of the M-electrode **120** becomes exposed at the surface of the first principal plane of the first molded section **150**. Also, the heat release plane of the heat-releasing section **131** of the P-electrode **130**, the heat release plane of the lead wire **132**, and the heat release plane of the heat-releasing section **141** of the N-electrode **140** become exposed, in juxtaposed form in the long-side direction, at the surface of the second principal plane of the first molded section **151**, since the heat-releasing section **131** of the P-electrode **130**, the lead wire **132**, and the heat-releasing sections **141** of the N-electrode **140** are arranged on the same plane. Additionally, the lead wire **122** of the M-electrode **120**, the lead terminal **123**, the G-wires **160**, **162**, and the S-wires **161**, **163** are routed outward from the first longitudinal principal plane of the first molded section **151**. Furthermore, the lead wire **133** of the P-electrode **130** and the lead terminal **143** of the N-electrode **140** are routed outward from the second longitudinal plane of the second molded section **152**.

The mold resin has an electrical insulating property, and when used to fill the fourth assembly, the mold resin provides electrical insulation between the M-electrode **120**, the P-electrode **130**, the N-electrode **140**, the G-wires **160**, **162**, and the S-wires **161**, **163**.

The screw hole **135** provided in the lead terminal **133**, and the screw hole **146** provided in the lead terminal **143** are formed at opposite positions in the long-side direction. Thus, when the lead terminals **133** and **143** are opposed to each other, the screw holes **135** and **146** skew with respect to each other in the long-side direction.

According to the present embodiment described above, the N-electrode **140** is bent at the first bend **144** in the direction opposite to the P-electrode **130**, the lead wire **132** of the P-electrode **130** and the lead wire **142** of the N-electrode **140** are opposed in parallel to each other in proximity to the bending direction of the N-electrode **140**, and the lead terminals **133** and **143** are opposed in parallel to each other. Therefore, when a positive current flows into the lead wire **132** and the lead terminal **133** and a negative current equal to the positive current in magnitude and opposite in direction flows into the lead wire **142** and the lead terminal **143**, a magnetic field generated by the positive current can be offset by a magnetic field generated by the negative current. Thus, according to the present embodiment, the magnetic field offset effect makes it possible to reduce the line inductance developed between the lead wire **132**, **142** and the lead terminal **133**, **143**.

FIGS. **6** and **7** show more specifically a line inductance reduction effect obtainable in the above configuration. An example in which the IGBT **111** at the upper-arm side is switched from off to on is described below in the present embodiment.

As shown in FIG. **6**, line inductance **106** exists between the collector electrode line (lead wire **132** and lead terminal **133**) of the upper-arm IGBT **111** and the emitter electrode wiring (lead wire **142** and lead terminal **143**) of the lower-arm IGBT **111**. Also, line inductance **105** exists between the positive and negative lines of the capacitor device **102**, as shown in FIG. **6**. The electric circuit device **110** of the present embodiment is constructed so as to reduce the line inductance **106**. As described later herein, the line inductance **115** is also reduced in the present embodiment.

When the upper-arm IGBT **111** is switched from off to on, a recovery current **107** routed from the DC positive-polarity side through the upper-arm IGBT **111** and the lower-arm diode **112** to the DC negative-polarity side flows into the arm for a moment. The arrow of a solid line, denoted as reference number **108**, indicates a load current that flows when the upper-arm IGBT **111** is in a turn-on state.

As shown in FIG. **7**, the recovery current **107** in the electric circuit device **110** flows from the led terminal **133** of the P-electrode **130** into the lead terminal **143** of the N-electrode **140**. At this time, recovery currents that flow into the lead wire **132** and the lead wire **142** of the N-electrode **140** are equal in magnitude and opposite in direction. Recovery currents that flow into the lead wire **133** of the P-electrode **130** and the lead wire **143** of the N-electrode **140** are also equal in magnitude and opposite in direction. At the opposed sections described above, therefore, a magnetic field generated by the recovery current flowing into one side is offset by a magnetic field generated by the recovery current flowing into the other side, and the line inductance **106** is resultingly reduced.

Essentially the same effect as the above, is also expected to be obtainable when the upper-arm IGBT **111** is switched from on to off, when the lower-arm IGBT **111** is switched from off to on, and when the lower-arm IGBT **111** is switched from on to off.

According to the present embodiment, therefore, since the line inductance **106** in the electric circuit device **110** can be reduced, loss during the switching of the IGBT **111** can be reduced and the amount of heat generated thereby can also be reduced. Hence, according to the present embodiment, the electric circuit device **110** can be constructed using a more compact semiconductor chip that constitutes the IGBT **111**, and thus the electric circuit device **110** can be miniaturized.

Additionally, according to the present embodiment, the semiconductor chips constituting the upper-arm IGBT **111** and diode **112** are sandwiched using the P-electrode **130** and the M-electrode **120**, and the semiconductor chips constituting the lower-arm IGBT **111** and diode **112** are sandwiched using the N-electrode **140** and the M-electrode **120**. Furthermore, the plane opposite to the mounting surface of the semiconductor chips of the P-electrode **130** and M-electrode **120**, and the plane opposite to the mounting surface of the semiconductor chips of the N-electrode **140** and M-electrode **120** are exposed as heat release planes, at the surface of the first molded section **151**. The heat generated by the semiconductor chips can be released from both chip surfaces thereof to outside via each electrode. This makes it possible, according to the present embodiment, to release a greater amount of heat from the semiconductor chips and improve cooling capabilities of the electric circuit device **110**. Hence, according to the present embodiment, the electric circuit device **110** can be constructed using smaller semiconductor chips that constitute the IGBTs **111** and the diodes **112**, and thus the electric circuit device **110** can be miniaturized.

As described above, the present embodiment makes it possible to achieve line inductance reduction in the electric circuit device **110** and the improvement of its cooling capabilities at the same time.

Next, a configuration of an actual inverter **100** (**300**) with the above-described electric circuit device **110** mounted therein will be described using FIGS. **8** to **18**.

The inverter **100** (**300**) includes a semiconductor module **101**, a capacitor device **102**, and a circuit board unit **190** constituting a controller **103**.

The semiconductor module **101** includes a heat release base **170** and an electric circuit device **110** mounted on the heat release base **170**.

The heat release base **170**, a heat-releasing element made of a metal excellent in thermal conductivity, such as aluminum, is a structure that includes a base unit for mounting and cooling the electric circuit device **110**, a collar constituting an installation section with respect to an enclosure, and a cooling fin **174** for cooling the capacitor device **102**. The base unit, the collar, and the cooling fin **174** are integrally formed by die-processing or cutting the above metallic material. The base unit is constructed of a block structure having a rectangular solid shape.

Hereinafter, in the present embodiment, when the base unit of the heat release base **170** is dimensionally maintained in a relationship of the depth is larger than the width and the height is smaller than the width, a depth direction of the base unit is defined as a longitudinal direction, a horizontal (width) direction as a lateral direction, and a height direction as a vertical direction or a thickness direction.

Centrally in the lateral direction of the base unit of the heat release base **170**, three electric circuit device insertion sections **172** extending upright in the vertical direction from a lower face **175**, towards an upper face **173**, are arranged in line in the longitudinal direction. Each electric circuit device insertion section **172** is of a rectangular cross-sectional shape. In this state, the electric circuit device insertion section **172** is provided so that a direction in which its long sides extend is the same as the longitudinal direction. Side walls **176** formed at both sides of the electric circuit device insertion section **172**, in the lateral direction thereof, each constitute a cooling surface. Each side wall **176** has a resin gate **177** at both ends in a longitudinal direction thereof, and centrally in the longitudinal direction. Each resin gate **177** is a cross-sectionally concave groove extending in the vertical direction. The resin gate **177**, a cross-sectionally concave groove extending in the vertical direction, is also formed centrally in a lateral direction of each side wall formed at both sides of the electric circuit device insertion section **172** in the lateral direction thereof. The resin gate **177** is used to pour resin into a clearance between the electric circuit device insertion section **172** and the electric circuit device **110** when the electric circuit device **110** is inserted into the electric circuit device insertion section **172**. The resin gate **177** is constructed so that the cross-sectionally concave groove avoids interference with the heat release planes of the electric circuit device **110**.

The base unit of the heat release base **170** internally has a cooling medium flow channel **171** at both ends in the lateral direction. The cooling medium flow channels **171** each extending through from one longitudinal side face to another are arranged at lateral positions in parallel so that each side wall **176** is sandwiched from both lateral sides, and so as to be parallel to the side wall **176**. Each cooling medium flow channel **171** is rectangular in cross-sectional shape. A coolant (water) flows as the cooling medium into the cooling medium flow channel **171**.

A longitudinal dimension of the electric circuit device insertion section **172** (i.e., a distance between the side walls **176**) is slightly larger than a dimension of the electric circuit device **110** in a thickness direction thereof (i.e., a distance between the first and second principal planes of the molded section **150**) when the electric circuit device **110** is inserted into the electric circuit device insertion section **172**. When the electric circuit device **110** is inserted into the electric circuit device insertion section **172**, therefore, a clearance is formed between the first principal plane of the first molded section **151** and one side wall **176** and between the second principal plane of the first molded section **151** and the other side wall **176**. These clearances are each filled in with resin **200** of high thermal conductivity.

The collars of the heat release base **170** are sections provided so as to protrude upward from both upper side faces of the base unit of the heat release base **170** in the lateral direction of the base unit, and the collars are constructed of a plate member having an L-shaped cross-sectional form. When the collars of the heat release base **170** are fixed to collars or installation portions of a metallic casing (not shown), the semiconductor module **101** is stored into the casing and fixed with the capacitor device **102** and the circuit board unit **190** remaining mounted in the module **101** (see FIG. **8**). The inside of the casing is hermetically enclosed by shrouding an opening of the casing with a metallic cover or lid, whereby the casing is waterproofed (water-sealed) and electromagnetically shielded.

The cooling fin **174** is a section provided so as to protrude perpendicularly in a downward direction from both lateral ends of the base unit lower face **175** of the heat release base **170**. The cooling fin **174**, an L-shaped plate member in cross section, is provided over entire longitudinal length of the base unit of the heat release base **170**. A plurality of screw insertion holes **179** are formed in a side wall of the cooling fin **174**. The screw insertion holes **179** are round through-holes extending through the side wall of the cooling fin **174** in a lateral direction thereof, and these holes are provided to insert screws from the side wall of the cooling fin **174** into a region surrounded thereby.

The electric circuit device **110** is inserted from the lower face **175** into the electric circuit device insertion section **172** and then insert-molded with the highly heat-conductive resin **200**. The electric circuit device **110** is positioned using the second molded section **152**. That is to say, since a dimension of the second molded section **152** in a thickness direction thereof is larger than the lateral dimension of the electric circuit device **110**, when the electric circuit device **110** is inserted from the lower face **175** into the electric circuit device insertion section **172**, the second molded section **152** abuts the lower face **175** and functions as a stopper.

The highly heat-conductive resin **200** has high thermal conductivity and an excellent electrical insulating property, and this resin is a mixture formed by, for example, impregnating epoxy resin with silica. The kind of substance with which to impregnate a resin agent such as epoxy resin can be alumina, aluminum nitride, boron nitride, or the like, instead of silica. The clearance between the first principal plane of the first molded section **151** and one side wall **176**, the clearance between the second principal plane of the first molded section **151** and the other side wall **176**, the clearance between the lower-stage step surface of the second molded section **152** and the lower face **175**, and internal spaces of the resin gates **177** are filled in with the highly heat-conductive resin **200** that has been poured via the resin gates **177**. Also, portions of the electric circuit device **110** exposed from the base unit upper face **173** of the heat release base **170** (i.e., the exposed portion at the first longitudinal side of the first molded section **151**, a portion of the lead wire **122**, and portions of the G-wires **160**, **162** and S-wires **161**, **163**) are covered with the highly heat-conductive resin **200** so that a range of packaging therewith is dimensionally greater than the opening in the electric circuit device insertion section **172**. Thus, the electric circuit device **110** is fixed in an electrically insulated condition to the base unit of the heat release base **170**. Additionally, the heat release planes of the electric circuit device **110** (namely, the principal plane side of the heat-releasing section **121**, the second principal plane side of the heat-releasing section **131**, **141** each, and that of the lead wire **122**) are thermally connected in an electrically insulated condition to the side wall **176**.

According to the present embodiment, since the heat release planes of the electric circuit device **110** (namely, the principal plane side of the heat-releasing section **121**, the second principal plane side of the heat-releasing section **131**, **141** each, and that of the lead wire **122**) are thermally connected in an electrically insulated condition to the side wall **176**, heat from both sides of the electric circuit device **110** is transferred to the side wall **176** via the highly heat-conductive resin **200** and then further transferred from the side wall **176** to the coolant flowing into the cooling medium flow channels **171**. According to the present embodiment, since both sides of each semiconductor chip inside the electric circuit device **110** can thus be cooled, cooling performance thereof can be improved and the electric circuit device **110** itself can be constructed using smaller semiconductor chips. According to the present embodiment, therefore, it is possible to miniaturize the electric circuit device **110** and thus to miniaturize the semiconductor module **101** in which the electric circuit device **110** is to be mounted.

At a lower section of the region surrounded by the cooling fin **174** is disposed the capacitor device **102**, at an upper section of which (i.e., an upper section close to the lower face **175**) are disposed the lead terminals **133**, **143** extending from the second longitudinal side of the second molded section **121**, towards the capacitor device **102**. The capacitor device **102** and the lead terminals **133**, **143** are electrically connected so as to match the polarities of the capacitor device **102** and those of the lead terminals **133**, **143**.

The capacitor device **102** includes a capacitor block **180**, a connection member **183**, a positive-polarity capacitor terminal **181**, a negative-polarity capacitor terminal **182**, and an electrical insulating sheet **184**. The positive-polarity capacitor terminal **181** and the negative-polarity capacitor terminal **182** are both formed using a flat-plate conductor made of a metal such as a copper alloy or copper excellent in thermal conductivity and in electrical conductivity. The connection member **183** is formed of an insulating member. Polybutylene telephthalate (PBT), for example, is used as the insulating member.

Hereinafter, in the present embodiment, the capacitor block **180** is referred to as the C-block **180**, the positive-polarity capacitor terminal **181** as the PC terminal **181**, and the negative-polarity capacitor terminal **182** as the NC terminal **182**.

The C-block **180** is a block structure of a rectangular solid shape, having a capacitor element in a casing. A longitudinal dimension of the C-block **180** is the same as that of the heat release base **170**. The C-block **180** has a lateral dimension that allows the C-block to lie properly in an internal space of the cooling fin **174**. Both lateral sides of the C-block **180** abut on an inner surface of the side wall of the cooling fin **174**. This arrangement causes the C-block **180** and the cooling medium flow channels **171** to be thermally connected via the heat release base **170**. Heat from the C-block **180** is transferred to the base unit of the heat release base **170** via the cooling fin **174** and then further transferred from the base unit to the coolant flowing into the cooling medium flow channels **171**.

A terminal unit that includes the PC terminal **181**, the NC terminal **182**, and the insulating sheet **184**, is disposed on an upper face of the C-block **180**. In terminal unit having the PC terminal **181** and the NC terminal **182** arranged in stacked form in the lateral direction with the insulating sheet **184** positioned between both, the PC terminal **181** and the NC terminal **182** protrude perpendicularly from a lateral central section of the C-block **180**, towards the lower face **175**, and extend in parallel in the longitudinal direction in association with the lead terminal **133**, **144**. The PC terminal **181** and NC terminal **182**, after protruding, are both bent outward (towards the opposite side to the sandwiching side of the insulating sheet **184**) in the respective lateral directions at right angles and then extend straightly. The PC terminal **181** and the NC terminal **182** are further bent at right angles towards the lower face **175**, then extend straightly, and face in the lateral direction in a longitudinally parallel condition via a spatial section. The insulating sheet **184**, after protruding, further extends straightly towards the lower face **175** and leads to a position closer thereto than to bends of the PC terminal **181** and the NC terminal **182**.

A screw hole **187** is formed in the PC terminal **181**. A screw hole **188** is formed in the NC terminal **182**. The screw hole **187** is a through-hole penetrating a terminal surface of the PC terminal **181** in a lateral direction thereof, and when the PC terminal **181** and the lead terminal **133** are connected, a position of an opening in the PC terminal **181** matches a position of an opening of the screw hole **135** in the lead terminal **133**. The screw hole **188** is a through-hole extending through a terminal surface of the NC terminal **182** in a lateral direction thereof, and when the NC terminal **182** is connected with the lead terminal **143**, a position of an opening in the NC terminal **182** matches a position of an opening of the screw hole **146** in the lead terminal **143**. For this reason, the screw hole **187** in the PC terminal **181** and the screw hole **188** in the NC terminal **182** are alternately arranged in the longitudinal direction.

The connection member **183** is disposed in the space formed between the PC terminal **181** and the NC terminal **182**. The connection member **183** is a block structure of a polyhedral solid shape, held in a sandwiched condition between the PC terminal **181** and the NC terminal **182** from both lateral sides thereof. The connection member **183** is used as an electrical insulating member between the PC terminal **181** and the NC terminal **182**, and as a connection member between the PC terminal **181**, the NC terminal **182**, and the lead terminal **133**, **144**. The block structure forming the connection member is formed up of a convex protrusion **186** disposed on the plane facing in the same direction as that of the lower face **175** of the rectangular solid, and a concave groove **185** disposed at the side of the capacitor block **180** of a rectangular solid shape. The protrusion **186** and the groove **185** are continuously provided in the longitudinal direction. A nut-containing portion **119** is formed at both sides in the lateral direction of the block structure which forms the connection member **183**. The nut-containing portions **119** are each a bottomed hexagonal hole opened from the lateral direction of the block structure, at both lateral sides thereof. When the connection member **183** is inserted into the space between the PC terminal **181** and the NC terminal **182**, a position of the above opening matches a position of the open screw hole **187**, **188**. For this reason, the nut-containing portion **119** at one side in the lateral direction of the connection member **183**, and the nut-containing portion **119** at the other side in the lateral direction are arranged in an offset condition in the longitudinal direction. Each nut-containing portion **119** contains a nut **189**.

Prior to electrical connection between the PC terminal **181** and NC terminal **182** of the capacitor device **102** and the lead terminals **133**, **143**, respectively, of the semiconductor module **101**, the connection member **183** is inserted into the space between the PC terminal **181** and the NC terminal **182** first. At this time, the lower face **175** of the insulating sheet **184** is engaged with the groove **185** of the connection member **183**. Next, the capacitor device **102** under the above state is inserted from the space at the lower face **175** into the region formed around the cooling fin **174**. The terminal unit that includes the PC terminal **181**, the NC terminal **182**, and the connection member **183**, is then sandwiched between the lead terminals **133**, **143** from both sides in the lateral direction. At this time, the lateral outer faces of the PC terminal **181** abut the first principal planes of each lead terminal **133**, and the lateral outer faces of the NC terminal **182** abut the second principal planes of each lead terminal **143**. That is to say, the terminals of the same polarity are interconnected. During the above insertion, the protrusion **186** of the connection member **183** is engaged with the groove **153** of the second molded section **152**. In addition, longitudinal positions of the screw holes **135**, **187** and the nut-containing portion **119** agree with those of the screw holes **146**, **188** and the other nut-containing portion **119**.

The section where the protrusion **186** of the connection member **183** is engaged with the groove **153** of the second molded section **152** is provided to ensure a creeping distance at an interface of the connecting portion between the connection member **183** and the electric circuit device **110** and thus to prevent electrical discharge. Also, the section where the groove **185** in the connection member **183** and the insulating sheet **184** become engaged with each other is provided to ensure a creeping distance at an interface of the connecting portion between the connection member **183** and the insulating sheet **184** and thus to prevent electrical discharge.

Next, the screw **109** is inserted into the screw hole **135**, **187** at one side in the lateral direction via the screw insertion hole **179** in the side wall of the cooling fin **174**. Thus, the screw **109** is threadably engaged with the nut **189** contained in the nut-containing portion **119** at one side in the lateral direction. The screw **109** is also inserted into the screw hole **146**, **188** at the other side in the lateral direction and threadably engaged with the nut **189** contained in the nut-containing portion **119** at the other side in the lateral direction. The screw insertion hole **179** provided at where it matches the screw hole **135**, **187** and the nut-containing portion **119** associated therewith is also provided at where it matches the screw hole **146**, **188** and the nut-containing portion **119** associated therewith. Also, the screw insertion hole **179** is larger than those screw holes in diameter. The above connecting operations can therefore be performed easily. Hence, the capacitor device **102** and the semiconductor module **101** can be electrically connected.

According to the present embodiment, the PC terminal **181** and the NC terminal **182** are opposed to each other in parallel, so when a positive current flows through the PC terminal **181** and a negative current equal to the positive current in magnitude and opposite in direction flows through the NC terminal **182**, the magnetic field generated by the positive current can be offset by the magnetic field generated by the negative current. Thus, according to the present embodiment, the magnetic field offset effect makes it possible to reduce the line inductance developed between the PC terminal **181** and the NC terminal **182**. That is to say, according to the present embodiment, the line inductance shown in FIG. **6** can be reduced.

According to the present embodiment, therefore, since the line inductance **105** in the capacitor device **102** can be reduced, it is possible to further reduce the switching loss of the IGBTs **111** and hence to further reduce the amount of heat generated by the IGBTs **111**. According to the present embodiment, therefore, the electric circuit device **110** can be constructed using even smaller semiconductor chips that constitute the IGBTs **111**. Thus, according to the present embodiment, the electric circuit device **110** can be miniaturized and the semiconductor module **101** in which to mount the electric circuit device **110** can be correspondingly miniaturized.

The circuit board unit **190** includes a control circuit board **191** and a plurality of electronic components mounted thereon.

The mounted electronic components are a microcomputer **192** that constitutes the foregoing control unit, a driver circuit (IC) **193** that constitutes the foregoing driver, and a current sensor **194** that detects a supply current to the foregoing semiconductor module **101**.

The control circuit board **191** is a rectangular flat plate, which is mounted on the base unit and collars of the heat release base **170** via spacers **197**. Also, the control circuit board **191** is fixed to the surfaces of the base unit and collars of the heat release base **170** by threadable engagement of screws **195** with screw holes **178**.

Three rectangular through-holes **196** extending through in a vertical direction of the control circuit board **191** are formed in line in a longitudinal direction thereof so that each through-hole **196** matches to the mounting position of one electric circuit device **110**. The through-hole **196** has an appropriate size such that the control circuit board **191**, when mounted on the base unit and collars of the heat release base **170**, fits onto the insert-molded electric circuit devices **110**. In the present embodiment, the insert-molded electric circuit devices **110** can thus be fixed using the control circuit board **191**. That is to say, the control circuit board **191** is used as a fixing jig in the present embodiment.

The microcomputer **192** is mounted at one side in a lateral direction of the through-holes **196** positioned centrally in the longitudinal direction of the control circuit board **191**. The driver **193** is provided for each upper arm and each lower arm. The driver **193** is therefore mounted on the control circuit board **191** so as to be disposed at both sides in the lateral direction of each through-hole **196**, and near the G-wires **160**, **162** and S-wires **161**, **163** of each electric circuit device **110** (i.e., at both sides in a longitudinal direction of the through-hole **196**). The current sensor **194** is mounted centrally at the through-holes **196** positioned at both longitudinal ends of the control circuit board **191** (i.e., the sensor **194** is mounted at a position associated with the lead wire **122** of each electric circuit device **110**). The lead wire **122** of the electric circuit device **110**, mounted at both longitudinal ends, extends through a hollow section of the current sensor **194**. The electric circuit device **110** and each electronic component are electrically interconnected by a wiring pattern and other wiring members provided on the control circuit board **191**. Connection between the electronic components is also established using the wiring pattern and other wiring members.

In the present embodiment, the microcomputer **192** and the driver circuit **193** are mounted on the same board, but both may be mounted on independent boards. In addition, while the control circuit board **191** in the present embodiment is mounted on the heat release base **170** via the spacers **197**, the board **191** may be mounted on the heat release base **170** without using the spacers **197**. In this case, since the control circuit board **191** and the heat release base **170** are thermally connected, the control circuit board **191** is expected to be cooled.

When the inverter **100** is assembled, each electric circuit device **110** that has been assembled in the manner described above is first insert-molded onto each heat release base **170** and then mounted thereon to construct the semiconductor module **101**. Next, as described above, the semiconductor module **101** and the capacitor device **102** are electrically connected. Finally, the control circuit board **191** with mounted electronic components is mounted on the heat release base **170**, and thus the inverter **100** is assembled.

As described above, according to the present embodiment, reduction in line inductance and the improvement of cooling performance by both-side cooling can be achieved at the same time. According to the present embodiment, it is thus possible to construct an electric circuit device **110** using semiconductor chips smaller than conventional ones, and hence to make the electric circuit device **110** more compact than conventional ones. The present embodiment, therefore, realizes the miniaturization of the semiconductor module **101** in which to mount the electric circuit device **110**, and furthermore, the miniaturization of the inverter **100** in which to mount the semiconductor module **101** itself.

According to the present embodiment, since the electric circuit device **110** is constructed for each arm, that is, on a two-in-one scheme basis, the mounting space of the electric circuit devices **110** in the semiconductor module **101** can also be reduced to achieve further miniaturization of the semiconductor module **101** and the inverter **100**.

In the present embodiment, a flow direction of the coolant in the semiconductor module **101**, input and output directions of current in the electric circuit device **110**, and a heat release direction of the semiconductor chips in the electric circuit device **110** are in an orthogonal relationship to one another.

Second Embodiment

A second embodiment of the present invention will be described per FIG. **21**.

The present embodiment, an improvement of the first embodiment, is an example of transposing the configurations of the P-electrode **130** and N-electrode **140** of the first embodiment. The present (second) embodiment differs from the first embodiment in three respects. One is that a configuration of a first bend **136** is added to the P-electrode **130** (however, the first bend **136** differs from the first bend **144** of the first embodiment in terms of position and is opposite in extending direction of a conductor). One is that the configuration of the lead wire **132** is replaced with a configuration of a lead wire **142** in the first embodiment (however, the lead wire **132** is opposite to the lead wire **142** of the first embodiment in terms of extending direction of a conductor). One is that since the first bend is removed from the N-electrode **140**, the configuration of the lead wire **142** is replaced with a configuration of a lead wire **132** in the first embodiment (however, the lead wire **142** is opposite to the lead wire **132** of the first embodiment in terms of extending direction of a conductor). Other elements are the same as those of the first embodiment in terms of configuration, so the same reference number or symbol is assigned to the same element, description of which is omitted.

In the present embodiment described above, as in the first embodiment, reduction in line inductance and the improvement of cooling performance by both-side cooling of semiconductor chips can be achieved at the same time and electric circuit devices **110** can be miniaturized.

Third Embodiment

A third embodiment of the present invention will be described per FIG. **22**.

The present embodiment, an application of the first embodiment, is an example of connecting arms' IGBTs **111** and diodes **112** in two lines in parallel. In the present (third) embodiment, the same pair of chips as that of HI and HD chips juxtaposed in a short-side direction are juxtaposed in a long-side direction, and the same pair of chips as that of LI and LD chips juxtaposed in a short-side direction are juxtaposed in a long-side direction. Along with these, the number of G-wires **160**, **162** and S-wires **161**, **163** is also correspondingly increased. In the present embodiment, various electrodes have areas larger than those of the electrodes in the first embodiment. Other elements are the same as those of the first embodiment in terms of configuration, so the same reference number or symbol is assigned to the same element, description of which is omitted.

In the present embodiment described above, as in the first embodiment, reduction in line inductance and the improvement of cooling performance by both-side cooling of semiconductor chips can be achieved at the same time and electric circuit devices **110** can be miniaturized.

According to the present embodiment, since the semiconductor chips are connected in two lines in parallel, each electric circuit device **110** can be increased in current density. In the same perspective, the number of parallel connection lines of the semiconductor chips can be increased to three and further to four, so the electric circuit device **110** can be further increased in current density.

Fourth Embodiment

A fourth embodiment of the present invention will be described per FIG. **23**.

The present embodiment, a modification of the first embodiment, is an example in which the HI and HD chips juxtaposed in the short-side direction in the first embodiment and the LI and LD chips also juxtaposed in the short-side direction in the first embodiment are each juxtaposed in a long-side direction. In the present (fourth) embodiment, the HD and LD chips are arranged more internally to an electric circuit device than the HI and LI chips. In the present embodiment, various electrodes have areas smaller than those of the electrodes in the first embodiment. Other elements are the same as those of the first embodiment in terms of configuration, so the same reference number or symbol is assigned to the same element, description of which is omitted.

In the present embodiment described above, as in the first embodiment, reduction in line inductance and the improvement of cooling performance by both-side cooling of semiconductor chips can be achieved at the same time and electric circuit devices **110** can be miniaturized.

According to the present embodiment, connecting the semiconductor chips in two, three, or four lines in parallel, as in the third embodiment, makes it possible to increase each electric circuit device **110** in current density.

Fifth Embodiment

A fifth embodiment of the present invention will be described per FIGS. **24** to **26**.

The present embodiment, another application of the first embodiment, is an example in which the semiconductor module **101** and capacitor device **102** in the first embodiment are connected together to form a basic unit **210** and multiple basic units **210** are arranged next to one another in a short-side direction. In the present (fifth) embodiment, three basic units **210** are juxtaposed for mutual contact between cooling fins **174** and are stored in a main unit casing **220**. Heat release bases **170** have no collars and are of lateral thickness smaller than in the first embodiment. C-blocks **180** also are of lateral thickness smaller than in the first embodiment. Other elements are the same as those of the first embodiment in terms of configuration, so the same reference number or symbol is assigned to the same element, description of which is omitted.

A unit terminal **240** is electrically connected to the C-block **180** (PC terminal and NC terminal) of each basic unit **210**. The unit terminal **240** protrudes in a longitudinal direction from a region formed between the cooling fins **174** of any two basic units **210**. The unit terminal **240** includes a positive-polarity terminal **241**, a negative-polarity terminal **242**, and an insulating sheet **243**. The positive-polarity terminal **241** and the negative-polarity terminal **242** are stacked vertically with the insulating sheet **243** sandwiched between both, and are opposed in proximity and in parallel to each other. After front ends of the positive-polarity terminal **241** and the negative-polarity terminal **242** have protruded longitudinally from the region formed between the cooling fins **174**, one of the front ends is bent at right angles outward in a vertical direction and then extends straightly, whereas the other front end is bent at right angles outward in a vertical direction and then extends straightly. A screw hole is formed at the respective front ends of the positive-polarity terminal **241** and the negative-polarity terminal **242**.

The unit terminals **240** are integratedly interconnected via an integrated terminal **230**. The integrated terminal **230** includes a positive-polarity electrode **234**, a negative-polarity electrode **236**, and an insulating sheet **233**. The positive-polarity electrode **234** and the negative-polarity electrode **236** are stacked vertically with the insulating sheet **233** sandwiched between both, and are opposed in proximity and in parallel to each other. Also, the positive-polarity electrode **234** and the negative-polarity electrode **236** both have a rectangular flat-plate laminate. A terminal **231** extending straightly towards one longitudinal side of the flat-plate laminate of the positive-polarity electrode **234** is formed at the particular longitudinal side, and three terminals **235** each bent at right angles towards one vertical side from the other longitudinal side and extending straightly is formed at the particular other longitudinal side. A terminal **232** extending straightly towards one longitudinal side of the flat-plate laminate of the negative-polarity electrode **236** is formed at the particular longitudinal side, and three terminals **237** each bent at right angles towards the other vertical side from the other longitudinal side and extending straightly is formed at the particular other longitudinal side. A screw hole is formed at the respective front ends of the terminals **231**, **233** and terminals **235**, **237**.

The front end of the positive-polarity terminal **241** of the unit terminal **240** and a terminal **235** abut each other in an opposed condition and are screw-connected. The front end of the negative-polarity terminal **242** of the unit terminal **240** and a terminal **237** abut each other in an opposed condition and are screw-connected. Thus, the C-blocks (PC terminals and NC terminals) of the same polarity are integratedly connected. The integrated electrode **230** is constructed so that current paths from the terminals **231**, **232** to the associated C-blocks **180** are equal in length.

The lead terminals **123** of each basic unit **210** are also integratedly connected for equal length of current paths on a phase-by-phase basis.

Since screw holes **221** are formed in the main unit casing **220**, the control circuit board with mounted electronic components can be mounted, as in the first embodiment.

The electric circuit devices **110** in the first embodiment may be replaced with those of any one of the second to fourth embodiments.

According to the present embodiment described above, since the multiple basic units **210** are integratedly connected using the integrated terminal **230**, reduction in line inductance and the improvement of cooling performance by both-side cooling of the semiconductor chips can be simultaneously achieved, as in the first embodiment. In addition, the electric circuit devices **110** can be made more compact and thus an inverter **100** of a larger capacity can be realized.

According to the present embodiment, since the integrated terminal **230** is constructed for equal length of the current paths extending from the terminals **231**, **232** to the C-blocks **180**, line inductance from the unit terminal **240** to the electric circuit device **110** can be well matched between the basic units **210**.

Sixth Embodiment

A sixth embodiment of the present invention will be described based on FIGS. **27** and **28**.

The present embodiment, a modification of the fifth embodiment, is an example in which the unit terminal **240** is provided at the bottom of the C-block **180**. For this reason, an opening **113** for exposing the unit terminal **240** is formed centrally at the bottom of the main unit casing **220** in a lateral direction thereof. The unit terminal **240** is essentially of the same configuration as in the fifth embodiment, except that the unit terminal **240** is rotationally moved through 90 degrees in a vertical direction of the terminal from a longitudinal direction thereof. The integrated terminal **230** also has the same configuration as in the fifth embodiment.

According to the present embodiment described above, since the multiple basic units **210** are integratedly connected using the integrated terminal **230**, reduction in line inductance and the improvement of cooling performance by both-side cooling of the semiconductor chips can be simultaneously achieved, as in the first embodiment. In addition, the electric circuit devices **110** can be made more compact and thus an inverter **100** of a larger capacity can be realized.

According to the present embodiment, since the integrated terminal **230** is constructed for equal length of the current paths extending from the terminals **231**, **232** to the C-blocks **180**, line inductance from the unit terminal **240** to the electric circuit device **110** can be well matched between the basic units **210**.

Seventh Embodiment

A seventh embodiment of the present invention will be described based on FIGS. **29** to **33**.

The present embodiment, another modification of the first embodiment, is an example in which the screw holes in the lead terminals **133**, **143** are formed as insertion portions **137**, **147** for welded bolts. For this reason, the C-block **180** has terminals stacked in a longitudinal direction with an insulating sheet **260** sandwiched between an PC terminal **261** and an NC terminal **262**. The PC terminal **261** and the NC terminal **262** have the welded bolts instead of screw holes. A concave groove **154** for engaging an insulating sheet **264** therewith is formed at the bottom of the second molded section **152**. Clearance **260** between the lead terminals **133**, **143** is smaller than in the first embodiment.

The groove **154** is provided to ensure a creeping distance at an interface of the connecting portion between the insulating sheet **264** and the electric circuit device **100** and thus to prevent electrical discharge.

In the present embodiment, the lead terminal **133**, **143** is used to engage the welded-bolt insertion portion **137**, **147** and the welded bolt **263** such that the terminals of the C-block **180** are sandwiched from both sides in the lateral direction. Also, a nut **264** is threadably engaged with the welded bolt **263** in that state. Thus, the lead terminal **133** and the lead terminal **143** abut on the P terminal **261** and the NC terminal **262**, respectively, and are linked together.

According to the present embodiment described above, the positive side and negative side at the connection between the lead terminal **133**, **143** and an associated terminal of the C-block **180** can be made closer to each other than in the first embodiment. Also, currents that flow through the positive and negative sides can be completely opposed with equal magnitude and opposite directionality. According to the present embodiment, therefore, line inductance can be reduced more significantly than in the first embodiment.

Eighth Embodiment

An eighth embodiment of the present invention will be described per FIGS. **34** and **35**.

The present embodiment, yet another modification of the first embodiment, is an example in which both-side cooling and line inductance reduction can be achieved at the same time without using the first bend **144** of the N-electrode **140**. For this reason, the present embodiment provides metallic spacers **270** and **271** of a rectangular flat-plate shape that are made of copper excellent in electrical conductivity and in thermal conductivity. The metallic spacer **270** is connected between the chip surface at the emitter electrode side of an HI chip, the chip surface at the anodic electrode side of an HD chip, and the mounting surface of the heat-releasing section **121**, and the metallic spacer **271** is mounted on the heat release plane of the heat-releasing section **141**.

The heat-releasing section **141** is disposed on the same plane as that of the lead wire **142**. Therefore, the heat release plane of the heat-releasing section **141** cannot be exposed at the second principal plane of the first molded section **151**. Instead, a second principal plane of the metallic spacer **271** serves as the heat release plane of the heat-releasing section **141** and is exposed at the surface of the second principal plane of the first molded section **151**.

The metallic spacer **270** may be disposed integrally with the M-electrode **120**.

In the present embodiment described above, as in the first embodiment, reduction in line inductance and the improvement of cooling performance by both-side cooling of semiconductor chips can be achieved at the same time and electric circuit devices **110** can be miniaturized.

According to the present embodiment, connecting the semiconductor chips in two, three, or four lines in parallel, as in the third embodiment, makes it possible to increase each electric circuit device **110** in current density.

What is claimed is:

1. A power convertor comprising:

a first semiconductor chip constituting an upper arm;

a second semiconductor chip constituting a lower arm;

a capacitor device supplying DC power to the first semiconductor chip and the second semiconductor chip;

a P-electrode comprising a first lead wire connected to the first semiconductor chip and a first lead terminal connected to a positive-polarity capacitor terminal of the capacitor device;

a N-electrode comprising a second lead wire connected to the second semiconductor chip and a second lead terminal connected to a negative-polarity capacitor terminal of the capacitor device; and

a M-electrode connecting the first semiconductor chip with the second semiconductor chip;

wherein the first semiconductor chip, the second semiconductor chip, the capacitor device, the P-electrode, the N-electrode, and the M-electrode constitute a closed circuit,

the first lead terminal and the second lead terminal are laminated and disposed with a connection member sandwiched between the first lead terminal and the second lead terminal, and

the P-electrode, the first semiconductor chip, the M-electrode, the second semiconductor chip, and the N-electrode are laminated and disposed so that adjacent currents flow through the first lead wire, the M-electrode, and the second lead wire respectively in opposite directions to each other if a closed current flows through the closed circuit.

2. A power converter according to claim **1**, wherein

the first semiconductor chip comprises a first IGBT and a first diode,

the second semiconductor chip comprises a second IGBT and a second diode,

a first gate wire connected to the first IGBT is disposed to protrude in the opposite direction to the protruding direction of the first lead terminal, and

a second gate wire connected to the second IGBT is disposed to protrude in the opposite direction to the protruding direction of the second lead terminal.

3. A power converter according to claim **1**, wherein

the connection member includes a first nut, and

the second lead terminal is fixed to the connection member by a first screw connected to the first nut.

4. A power converter according to claim **1**, wherein

an electric circuit device comprises the first semiconductor chip, the second semiconductor chip, a first heat release section and a second heat release section facing the first heat release section with the first semiconductor chip and the second semiconductor chip disposed between the first heat release section and the second heat release section,

the first lead terminal and the second lead terminal are connected to a first surface of the electric circuit device facing capacitor device, and

the electric circuit device has an alternating current side terminal connected to a second surface which is different from the first surface of the electric circuit device.

5. A power converter according to claim **1**, further comprising molded material sealing the first semiconductor chip, the second semiconductor chip, the first lead wire, and the second lead wire.

6. A power converter according to claim **3**, wherein

the connection member includes a second nut, and

the first lead terminal is fixed to the connection member by a second screw connected to the second nut.

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